McGRAW-HILL PUBLICATIONS IN THE AGRICULTURAL SCIENCES
R. A. BRINK, CONSULTING EDITOR

SOILS AND SOIL MANAGEMENT

McGRAW-HILL PUBLICATIONS IN THE AGRICULTURAL SCIENCES

R. A. BRINK, CONSULTING EDITOR

ADRIANCE AND BRISON · Propagation of Horticultural Plants
AHLGREN · Forage Crops
BROWN · Cotton
CARROLL AND KRIDER · Swine Production
CRUESS · Commercial Fruit and Vegetable Products
DICKSON · Diseases of Field Crops
ECKLES, COMBS, AND MACY · Milk and Milk Products
ELLIKER · Practical Dairy Bacteriology
FERNALD AND SHEPARD · Applied Entomology
GARDNER, BRADFORD, AND HOOKER · The Fundamentals of Fruit Production
GUSTAFSON · Conservation of the Soil
GUSTAFSON · Soils and Soil Management
HAYES, IMMER, AND SMITH · Methods of Plant Breeding
HEALD · Manual of Plant Diseases
HEALD · Introduction to Plant Pathology
HERRINGTON · Milk and Milk Processing
HUTT · Genetics of the Fowl
JENNY · Factors of Soil Formation
JULL · Poultry Husbandry
LAURIE AND RIES · Floriculture
LEACH · Insect Transmission of Plant Diseases
MAYNARD · Animal Nutrition
METCALF, FLINT, AND METCALF · Destructive and Useful Insects
NEVENS · Principles of Milk Production
PATERSON · Statistical Technique in Agricultural Research
PETERS AND GRUMMER · Livestock Production
RATHER AND HARRISON · Field Crops
RICE AND ANDREWS · Breeding and Improvement of Farm Animals
ROADHOUSE AND HENDERSON · The Market-milk Industry
ROBBINS, CRAFTS, AND RAYNOR · Weed Control
SCHILLETTER AND RICHEY · Textbook of General Horticulture
STEINHAUS · Principles of Insect Pathology
THOMPSON · Soils and Soil Fertility
THOMPSON · Vegetable Crops
WALKER · Diseases of Vegetable Crops
WALKER · Plant Pathology
WILSON · Grain Crops
WOLFE AND KIPPS · Production of Field Crops

The late Leon J. Cole was Consulting Editor of this series from 1937 to 1948.

There are also the related series of McGraw-Hill Publications in the Botanical Sciences, of which Edmund W. Sinnott is Consulting Editor, and in the Zoological Sciences, of which Edgar J. Boell is Consulting Editor. Titles in the Agricultural Sciences were published in these series in the period 1917 to 1937.

SOILS AND SOIL MANAGEMENT

BY

A. F. GUSTAFSON

Late Professor Emeritus of Soil Technology, New York State College of Agriculture, at Cornell University

McGRAW-HILL BOOK COMPANY, INC.

NEW YORK AND LONDON

1941

PREFACE

The purpose of this book is the presentation of information dealing with the management of soils in the field. Emphasis is placed on ways and means of handling soils for economic production of crops. The volume was written for the student of practical soil management on the farm and in the classroom. In addition, it should be helpful alike to owners and operators of land.

The management and fertilization of soils are fully treated, but the conservation of the soil can be only outlined within the scope of this volume. The content of this work, with some variation in emphasis and order of presentation, has been used by the author in the classroom over a period of years. Sources of information are credited and references given for the benefit of the reader.

Dr. Alfred Smith of the Division of Soil Technology in the University of California collaborated on the sections that deal with Irrigation, Dry Farming, and the Management of Alkali Soils of Arid and Semiarid Regions and read the entire manuscript. Dr. E. V. Staker of the Department of Agronomy in Cornell University collaborated on Chapter XIX. The author is also indebted to Dr. Ralph W. Cummings, Mr. C. M. Jones, Dr. J. K. Wilson, and Professor A. M. Goodman, all of Cornell University, who read and criticized the manuscript.

This book is presented in the hope that it may aid in bringing about better management, more adequate fertilization, and more nearly complete conservation of the soil.

The many helpful suggestions made by fellow workers are gratefully acknowledged.

A. F. GUSTAFSON.

ITHACA, N. Y.
January, 1941.

CONTENTS

SOILS AND SOIL MANAGEMENT

INTRODUCTION

During his entire existence upon the earth, man has depended upon the soil, either directly or indirectly, for the production of the materials used by him for food and clothing and, in part, for the production of those used for fuel and shelter as well. Grains, fruits, and vegetables that serve him as food grow directly on the soil. Cotton[1] and flax yield materials that are made into clothing. Trees and many other plants, also direct products of the soil, supply food and materials for industries and for buildings for sheltering man and his domestic animals.

Likewise, the grain and forage crops that constitute the feed consumed by domestic animals are immediate products of the soil. The animals in turn contribute meat, milk, eggs, and other products that are used for human food and, in addition, wool, silk, and hides for the manufacture of clothing.

In highly favored sections of the world, man obtains fuel in the form of coal, oil, or gas from the depths of the earth. All these have resulted from the growth of plants on ancient soils during the long geological ages that preceded the advent of man.

Thus it appears obvious that for his well-being, in fact for his very existence, man is dependent in large measure upon the soil. Truly, the indefinite continuance of human life upon the earth is conditioned by rational use of the soil, that is, by its wise management, its adequate fertilization, and, more particularly, its true conservation.

In the past and even at present, owners of land have treated the soil as they pleased. In periods of low crop prices, farmers are forced to overwork the land. This condition leads to soil

[1] The Latin or scientific names of plants mentioned in the text are found in the Appendix, page 405.

depletion through the removal of plant nutrients by cropping and the loss of soil by washing. The productive power of the soil may be reduced by overcropping and neglect, or it may be maintained at current levels or even increased by adopting suitable measures. Among these measures are the maintenance of desirable physical conditions in the soil, the return of organic matter, the application of phosphorus and other plant nutrients if needed, and liming, if necessary, for the growth of clover and other legumes. In addition, means of holding the soil in place will, of necessity, be adopted on sloping lands lest too much of the richer surface soil be washed away.

The owners and the tillers of the soil are under a definite obligation to society to preserve the productivity of the land that is temporarily under their control; and holding the soil itself against washing away is of still greater importance. Likewise, society has a mutual and equal obligation. On their part, the people must expect to pay such prices for farm produce as will compensate the farmer fairly. Compensation for his labor and additional returns are needed in order that he may maintain the power of the soil to supply human needs in the future as well as now. In many sections of the United States, plant nutrients have not been returned in the amounts that they have been removed by cropping and washing. To that extent, the farmer has robbed the soil of its native fertility. From this time on, in the older humid sections a larger return of nutrient materials to the soil is needed. Furthermore, because of low prices of farm products the farmer often does not possess the means with which to purchase the necessary fertilizer materials; adequate prices for the products of the land, therefore, are essential.

It appears to be a wise course for organized society not to allow or compel the farmer to deplete his soil to a serious extent, for upon its continued productivity depends the welfare of future generations.

For the production of crops, it is necessary that the farmer maintain conditions that are favorable for plant growth. The general adoption and the faithful following of all the more important management, fertilization, and conservation practices should ensure a reasonable degree of productivity of the soil for many years. The succeeding pages deal with the problems of soil management.

Questions

1. In what respects is man dependent upon the soil?

2. What is the relative importance of maintaining the productivity of the soil and of holding the soil itself in place against erosion?

3. How do low crop prices affect depletion and erosion of the soil?

4. What obligation has society to owners and operators of land, and what do they in turn owe to society?

CHAPTER I

THE ORIGIN AND PLACEMENT OF SOIL MATERIALS AND SOIL FORMATION

Over the surface of the earth is a layer, or blanket, of unconsolidated material that was formed from the rocks of the outer part of the earth's crust. With the exception of steep mountain and hillsides and local areas that were swept clean by glacial or stream action, the bedrock everywhere is covered with this debris. In many places, this debris resembles the parent rock in chemical and physical composition. In other areas, the changes have gone so far that little resemblance or relationship to the parent rock can be detected. And all intermediate stages may be expected.

The soil materials often vary, also, because of the influence of the different agencies that produced them. Moreover, other forces may have transported these materials and in so doing sometimes separated and assorted them. Thus, beds of sand and gravel and many surface deposits of clay and silt were formed. The soil material varies in thickness from a few inches to 20 or 30 feet and attains depths of 100 or even 200 feet in some areas.

The marked variations in elevation and topography in this country may be seen on the relief map of the United States (Fig. 1). The locations of the large areas of land with topography suitable for agriculture are shown here.

THE ORIGIN OF SOIL MATERIALS

The occurrence of the unconsolidated rock material over the land surface of the earth is evidence of the effectiveness of the agencies of *weathering*. By weathering is meant the changing of fresh rock into the mantle of material that covers the bedrock. The agencies of weathering may be divided into two classes, physical and chemical.

Physical Agencies.—The physical agencies are responsible for reducing massive rock to the sizes of particles that constitute soil materials, in other words, for the *disintegration* of rocks. Tem-

Fig 1 —Relief map of the United States A glance at the relief map of the United States indicates the location of the large areas of land that are suitable for agriculture (*Courtesy of U S Geological Survey*)

perature changes tend to break up the surface, particularly of coarse-grained rocks. After the grains have been loosened somewhat, water enters; upon freezing, it expands and pushes the grains still farther apart. In time, as disintegration continues, other agencies remove the loosened grains, and the process continues.

Such forces as streams, winds, waves, glaciers (Fig. 2), and lake- and ocean-shore currents in moving materials about cause

Fig. 2.—Giekie Glacier, southeastern Alaska. Note the immense quantities of glacially produced rock flour and coarser material in the foreground. Such material eventually weathers to soil. (*Courtesy of U. S. Geological Survey.*)

much grinding of stones, gravel, and smaller particles against each other. As a result of this action, much fine soil material has been produced.

Minor work is done by plants and animals. The roots of plants enter crevices and wedge rocks apart, thus giving other agencies an opportunity for work. Animals burrow in the soil and bring about some grinding of soil materials. The mixing of organic matter with the soil is an important part of the work of plants and animals.

Chemical Agencies.—Whereas the physical agencies change the size of rock materials, primarily, the chemical agencies alter the

FIG 3 —Deposits of calcium carbonate These stones are mainly noncalcareous The light-colored material on them is calcium carbonate which was dissolved from limestone and other calcium-bearing gravel above them Upon evaporation of the water the bicarbonate was deposited as calcium carbonate. Gravel and boulders are often cemented together in this manner

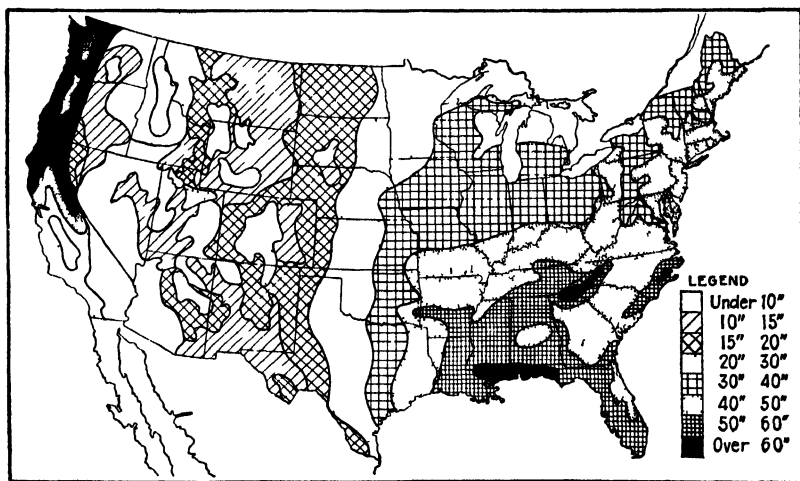



FIG 4 —Precipitation map of the United States The different shadings show the quantity of precipitation (water in all forms) in inches on the average for a period of years. (*Redrawn from data supplied by the U S Weather Bureau*)

composition of the material. The effects of these chemical changes are termed *decomposition*. Some of the more readily soluble compounds of the metals may be brought into solution (Fig. 3). These compounds may then be leached downward or out of the soil material by rain water (Fig. 4). The oxidation, or the taking up of oxygen, by certain materials alters their hardness and often increases their volume. The hydration, or the taking up of water, increases the volume and softens certain compounds in the soil material. These and other chemical reactions in the material make it profoundly different from the parent rock.

The whole process of weathering, therefore, is one of disintegrating, or reducing, rocks to finer materials and through chemical reactions increasing the solubility of certain portions of the mass of weathering rock material.[1]

The Rate of Weathering of Rocks.—Considerable variation exists in the rate of weathering of different rocks under similar conditions and of similar rocks under different conditions. The coarse-textured rocks disintegrate more rapidly than do the fine-grained ones. And the granular rocks generally disintegrate more rapidly than do the glassy, nongranular ones. Because of their greater absorption of heat, dark-colored rocks are subject to greater differences in temperature than light-colored ones. Consequently, the dark-colored rocks undergo relatively more rapid disintegration on their surfaces than do similar light-colored ones.

Moreover, rocks that contain an *element of weakness* are particularly susceptible to weathering. As examples of weakness may be mentioned some of the more readily soluble compounds of calcium, magnesium, potassium, and sodium. Other examples are compounds of iron which change in hardness and which increase in volume as a result of oxidation and hydration, as previously pointed out. As the combined result of the action of the various physical and chemical agencies, rocks weather at markedly different rates. Some break down easily, and others are decidedly resistant to weathering.

[1] Extended information on the weathering of rocks to soil material may be found in textbooks on geology. Attention is called to "Agricultural Geology" by H. L. Emerson, 1928; the older work, "Rocks, Rock Weathering, and Soils" by G. P. Merrill, 1913, and "The Nature and Properties of Soils" Chaps. I and II, by T. L. Lyon and H. O. Buckman, 1937, published in New York by The Macmillan Company.

THE PLACING OF SOIL MATERIALS AND THE RESULTING FORMATIONS

Two general types of soil material are recognized, those which rest in the place where they were formed and those which have been moved from the place of formation to their present location.

Fig. 5.—Residual soil. This productive surface soil gradually becomes less and less weathered and finally gives way to fresh underlying rock. (*Courtesy of John T. Auten.*)

The former are called *sedentary* materials and the latter *transported* ones.

Sedentary Materials.—Sedentary materials are of two distinct kinds: the inorganic, mineral, or *residual* materials; and the organic, or *cumulose*, deposits.

Residual Soil Materials.—The residual soil materials are of great importance because of the immense area they occupy, not

only in this country but throughout the world. In humid regions, some of the soluble material has been leached away. The relatively insoluble residues, therefore, constitute the unconsolidated surface material (Fig. 5).

In the United States, the residual deposits occupy the area south of the glaciated region (Fig. 11) and east of the Mississippi River. In addition, much of the southern part of Missouri, the northwestern part of Arkansas, the southeastern part of Oklahoma, and other areas to the westward are occupied by residual material. The Atlantic and Gulf Coastal plains are, of course, not strictly residual material, having been deposited by streams on the higher part of the continental shelf. Since the material was only slightly consolidated, it weathered readily to soil material when elevated above sea level.

The parent rock still has some influence on the constitution of the more youthful, residual materials. The material from limestones consists of the impurities that were included in the original rock and is mainly clay, silt, sand, and chert particles. Through solution, the calcium and magnesium have been removed in the form of bicarbonates. Obviously, since leaching has been intense over geological time, the residual deposit is essentially free of calcium and magnesium in the carbonate form.[1] A yellow, grayish-yellow, or reddish-yellow color is characteristic of heavy, residual material from limestones.

Materials from granites low in quartz and from shales, gabbro, and diabase also are usually heavy or clayey in nature. In contrast, the residual material from granite that is high in quartz and from sandstones is predominantly sandy in nature. Also, in contrast to limestones, where the residual material lies directly on the fresh rock, a granite may be strongly weathered on the surface and progressively less and less weathered downward. In places where little of the weathered surface material has been removed by erosion, the transition from soil material to the fresh rock may occur through 50 to 100 feet or more.

[1] Consider, for example, a limestone that originally contained a total of 95 per cent of calcium and magnesium carbonates and 5 per cent of impurities, clay, and fine sand. If the resulting residual soil is 30 feet in depth, it is clear that 600 feet of this limestone must have been decomposed and the soluble material leached away. This is, of course, based on the assumption that none of the residual material has been carried away by erosion.

Cumulose Soil Materials.—The term *cumulose* has been applied to accumulations of organic matter in lakes, ponds, and swamps. Various low forms of plants including sphagnum moss laid the foundation for these deposits. As the material under the surface died, it settled to the bottom and finally filled the body of water with organic matter. Later, higher forms of water-loving, or hydrophytic, plants gained a foothold and gradually built up the surface of the deposit above the normal water level. In time, shrubs and trees came in and grew luxuriantly on this material. Varying quantities of mineral matter such as silt and clay were carried into these bodies of water during the long period of accumulation of the organic matter. The soils formed from these organic deposits receive consideration in Chap. XIX.

Transported Materials.—Transported materials were brought to their present position by such agencies of transportation as gravity, ice, water, and wind. These agencies have been actively shifting soil materials about almost continuously throughout the ages.

Materials transported primarily by gravity are known as *colluvial* deposits, by ice as *glacial*, in lakes as *lacustrine*, by streams as *alluvial*, by waves as *marine*, and by wind as *aeolian*. It is conceivable that soil material may at one time or another have been transported in turn by several of these agencies. Materials are classified, however, under the agency that was responsible for their present location. A few examples may be helpful. Ice sheets picked up and moved forward colluvial material which in turn became glacial debris. The finer portion of this may have been assorted and carried far beyond the limit of the ice by streams, the deposit then being classed as alluvial. During dry periods, the wind picked up and spread this fine alluvial material over the upland where it now rests as aeolian material.

Colluvial Materials.—Colluvial materials were moved from their point of origin primarily by gravity. The familiar example is the talus, or rock debris, at the base of cliffs or slopes. Strictly colluvial deposits are confined to areas of steep topography and, more particularly, to mountainous areas. Talus materials are usually so coarse and dry that they do not ordinarily develop into productive soils (Fig. 6).

Glacial Materials.—In addition to producing a tremendous quantity of soil-forming material, glaciers picked up the pre-

viously formed residual soil material and mixed it with freshly ground-up rocks. The debris carried by the glacial ice, therefore, was a highly variable mixture of old soil and freshly reduced rock material. Consequently, varying periods were required for the weathering of this debris.

Glacial materials have different names in accord with their location in relation to the glacier as a whole. At times during

Fig. 6.—Colluvial or talus material. Upon weathering, the loosened rock rolls down the steep slope. This material, although heterogeneous in size, is mainly rather coarse and does not weather quickly to productive soils. (*Courtesy of U.S. Geological Survey, W. T. Lee.*)

the waning stage, the front of the ice appears to have moved back and forth over a relatively narrow zone. As the ice thawed, the material it carried was deposited as a broad, indefinite ridge. Because it marked the extreme limit of advance, this ridge is called the *terminal* moraine.

The latest glacier that covered large areas in this country thawed back somewhat rapidly a considerable distance from the terminal moraine. A period of slow thawing followed, and

another ridge called a *recessional* moraine was built up. Similar material at one edge of a glacial lobe is sometimes called a *lateral* moraine.

When the ice disappeared, the material it carried was left as a mantle of rock debris over the area the glacier had covered. The debris was a mixture of the fine and coarse materials. This heterogeneous deposit is variously called *ground moraine, glacial debris* or *till,* or *boulder clay.* The ground moraine, which is

FIG. 7.—Ground moraine (Honeoye loam in New York). Ground moraine or glacial till is unassorted material and consists of a mixture of boulders and clay together with all of the intermediate sizes of particles. Much larger boulders than these are often found in the ground moraine.

variable in thickness, parent material, and topography, is by far the most extensive of the glacial deposits (Fig. 7).

Another type of glacial formation called *drumlin* is found in various places including New York, Michigan, and Wisconsin. Drumlins are more or less pear-shaped, elongated hills usually composed of unassorted till (Fig. 8).

It appears that glacial streams sometimes flowed in cracks in the ice and carried much gravel and coarse sand. When the ice disappeared, it left the gravel as long serpentine ridges called *eskers.* They are well developed in parts of Wisconsin, Michigan,

and New York. Another type of gravel deposit is the *kame*, which occurs as rounded hills and ridges.

During thawing, immense quantities of water flowed from the front of the ice. The coarse material was deposited first and the

FIG. 8.—Drumlin, Wayne County, New York. Drumlins consist mainly of unassorted material, yet some drumlins show a distinct lake influence. (*Courtesy of H. O. Buckman.*)

FIG. 9.—Assorted gravel deposit, New York. The gravel shown here is glacial outwash. The stratification is essentially level. In kames, the layers often lie at rather sharp angles to the horizontal plane.

finer and finer in succession. This material is called an *outwash plain*. The northern part of Long Island, N.Y., is a series of kames. To the south is the outwash plain which slopes gently

and becomes finer toward the Atlantic Ocean. This is an example of an extensive outwash plain.

The same general type of deposit occurs in valleys like those found in southern New York. Where the valley sloped away from the ice, the water drained freely from it and the outwash-plain type of deposit was laid down (Fig. 9). Often streams developed a new flood plain in the old valley fill and left the outwash gravel as *second bottom,* or *terrace.*

Lacustrine Materials.—In some places, the land surface sloped toward the ice. Upon thawing, the water accumulated as a lake.

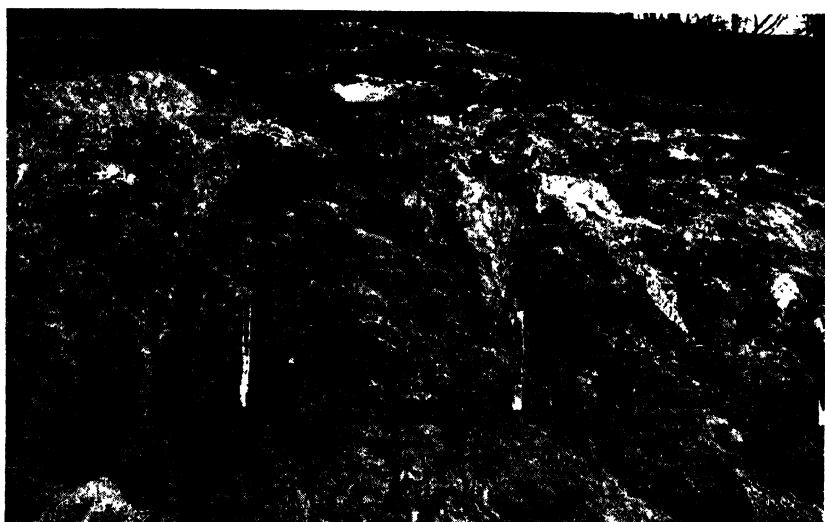



FIG. 10.—Lacustrine soil material. This material was laid down in lake water and consists typically of clay and silt. The soils formed from these deposits are relatively productive, yet lake-laid soils usually possess rather slow drainage.

Glacial water and precipitation on the land contributed soil material of all sizes. Near the shore of some sizable glacial lakes, streams deposited coarse materials as steep-faced *deltas.* The fine material was carried well out into such lakes and was finally deposited. This is called *lacustrine* material (Fig. 10).

The large glacial-lake beds in the East are associated with the Great Lakes both in Canada and in the United States. The Great Lakes, in fact, are remnants of what constituted one great inland body of water in late glacial time. Other such lakes are glacial Lake Agassiz in the Red River Valley in Minnesota and Manitoba, Lakes Lahonton and Bonneville mainly in Nevada

and Utah, and smaller ones over the glaciated area. The location and the extent of the larger areas of lacustrine materials are shown in Fig. 11.

Alluvial Materials.—Alluvial materials were moved to their present location by streams. The carrying power of streams, which is surprisingly great, is profoundly affected in a number of ways. If a grain of sand that has a specific gravity of 2.65 in the air is placed in water, it loses effective weight equal to that of the water it displaces. In water, therefore, it has an effective specific gravity of only 1.65 and may be carried easily by streams.

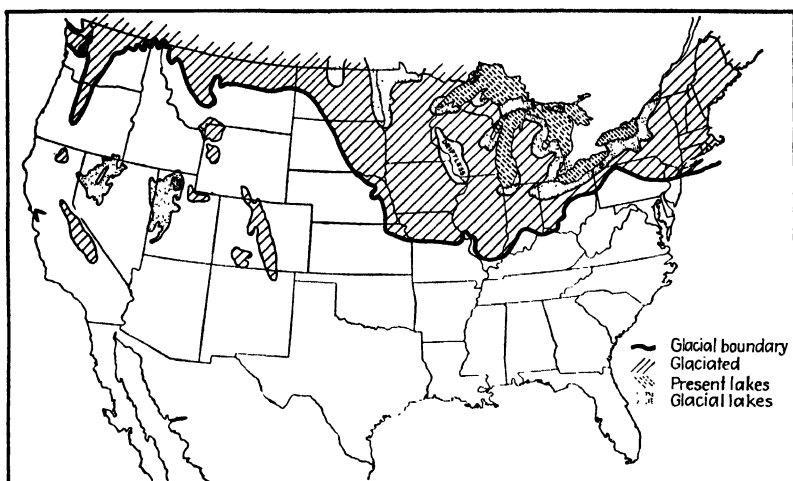



Fig. 11.—Extent and location of lake-laid and glacial soils in the United States. This map shows the areas of lake-laid soils in the United States together with the area formerly covered by glaciers.

In addition, there is the influence of the velocity of the current of the stream itself. The weight of individual particles borne in suspension by a current of water varies as the sixth power of its velocity. Doubling the velocity, therefore, enables a current to carry particles 64 times as heavy as before, and trebling increases by 729 times the weight of particles the faster current can carry.[1] In other words, if a current is carrying particles that weigh 0.01 gram, doubling its velocity enables the current to carry particles that weigh 0.64 gram, and trebling the velocity increases the weight of particles that can be carried to 7.29 grams. This

[1] 2 raised to the sixth power is 64. 3 raised to the sixth power is 729.

explains the well-nigh unbelievable transporting power of streams with steeply sloping beds in hilly and mountainous areas. Under these conditions, much additional coarse material is pushed and rolled along on the bed of streams.

The quantity of material a current can carry varies approximately as the fifth power[1] of its velocity. Doubling its velocity, consequently, enables a stream to carry 32 times, and trebling 243 times, as much total soil material as before. This information helps to explain the ability of streams to carry the immense quantities of soil material that they actually transport at flood stage.

FIG. 12.—Flood plain of the Rheidol River in Wales. These loops are characteristic of sluggish streams. Since the stream is one of low velocity, the first-bottom or alluvial soil would be expected to be rather heavy or fine-grained.

The area that is covered by streams at flood stage is called the *flood plain* or the *first-bottom* land (Fig. 12). The surface of the flood plain often is higher adjacent to the stream where low natural levees have been built up. This elevation is a result of the immediate deposition of the coarser materials carried, since the velocity of the current is checked somewhat whenever the

[1] DEACON, G. F., Discussion on Training Rivers, *Minutes Proc. Inst. Civil Eng. (London)*, Vol. 118, p. 95, 1894.

stream overflows its banks. The material becomes increasingly finer as the lowest part of the flood plain is approached.

Wherever a steep-bedded side stream spreads its water over the flood plain of a larger stream, the slope in the channel of the side stream suddenly flattens out. And in contrast to the effect of increasing speed which was accompanied by enlarged carrying capacity, precisely the opposite occurs when the velocity of a stream is checked. Since the carrying capacity of the side stream is reduced, it deposits the largest stones or gravel first.

Fig. 13.—Sand dunes with "blowouts." Grasses or forest trees often cover sand and hold it in place. If the cover is broken, however, the wind moves the sand and "blowouts" result. Often blowing is so active that vegetation unaided is unable to reestablish itself. Methods of stabilization are discussed in Chap. X. (*Photograph by the late J. G. Mosier.*)

Finer and finer materials are deposited as the velocity becomes slower and slower. Such deposits are called *alluvial fans* or, if very steep, *alluvial cones.* Streams on these fans characteristically occupy no definite channel for any considerable time. As one channel is filled, the water spreads over the fan until a new one is developed, only to be abandoned when clogged at any point by boulders and other obstructions.

Streams with slight fall tend to meander rather than to flow in relatively straight lines. After meandering is well under way, streams at flood stage tend to undercut their banks on sharp turns. As undercutting continues through the decades, the stream may cut through narrow necks of land, thus leaving the old channel as lagoons or lakes in the form of *oxbow loops.* These

loops no longer receive the water of the main stream except at flood stage, when they are filled with muddy water. As the water evaporates, the mud forms the soil material which, ordinarily, is rather fine and heavy in character.

Fig. 14.—A resurrected forest in Indiana. The forest was covered with sand that killed the trees. Some years later the dunes moved on and left the trunks of the dead trees exposed. (*Courtesy of G. F. Fix, Conservation Department, Indiana.*)

Certain large rivers, of which the Mississippi and the Nile are notable examples, deposit large quantities of soil materials in the sea. The Mississippi deposits its material in the Gulf of Mexico where it is not disturbed materially by shore currents. Upon contact with the salt water, the fine materials carried are precipitated and thus build up a *delta*. Delta materials often lack

drainage. If drainage can be provided, such deposits often develop into highly productive soils. In a similar way, small deltas developed where sizable streams entered inland lakes.

Marine Materials.—As already indicated, the waves on ocean shore lines have produced large quantities of relatively coarse soil materials because the fine particles were carried away by alongshore currents. As relatively flat shore lines are elevated above high tide, these materials develop into soils. In certain areas (Chap. XIX), plants grow to the extent of forming organic deposits. Marine deposits on the Atlantic and Gulf Coastal plains are of real importance in this country.

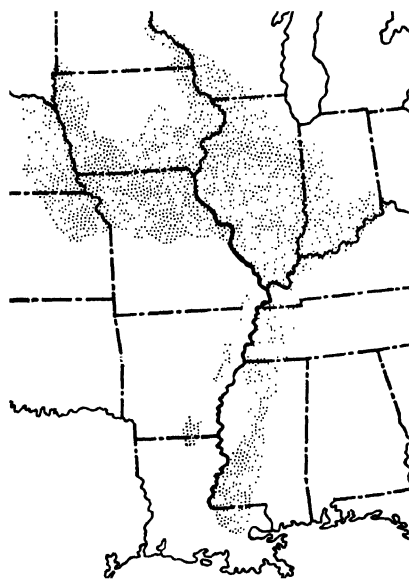



FIG. 15.—Location of aeolian soil materials—deep loess. The relation of the deep loess to the Mississippi and Missouri rivers is shown here. (*Drawn from data from various sources.*)

Aeolian Materials.—Aeolian materials were transported to their present location by the wind. These materials consist mainly of very fine sand and silt and of volcanic dust. Sand dunes are, perhaps, the most familiar wind-deposited material. They consist of alternate depressions and elevations. Certain depressions from which the wind has removed the sand are known as *blowouts.* The mound- or ridgelike elevations are called *dunes.* Any obstruction, such as a weed, a shrub, or a tree may check the wind and thus start dune formation. The movement of sand dunes is irresistible (Fig. 13). In Dune Park in Indiana, the sand buried forests. Later the sand moved on, and the remains of the trees were resurrected (Fig. 14). Likewise, productive land is often buried under sand of little value (see Chap. IX for control measures).

The important aeolian deposit from the agricultural standpoint in this country is *loess.* Its location indicates a close connection with the Mississippi and Missouri rivers. Figure 15

shows the location and the extent of the most important areas of loessal materials in the United States.

Streams flowing from the glaciers deposited immense quantities of medium-sized and fine particles. During dry periods, the wind picked it up and carried it some distance before redepositing it. Nearly two-thirds of the deep-loess particles are between 0.05 and 0.005 millimeters in diameter. This deeper loess stands in vertical escarpments for years (Fig. 16). If undermined, it falls off in slabs of uniform thickness.

FIG 16—A deep aeolian deposit deep loess in Illinois This deposit is from 30 to 50 feet deep and in places more than 100 feet. Vertical cleavage and walls such as these are characteristic of deep loess deposits.

Heavy clay when granulated is readily drifted by the wind. In the Midwest, granulated, heavy soils sometimes drift during winter and early spring to the extent that drainage ditches are filled and roads are covered. Coffey[1] reported finding clay dunes in southern Texas.

The material thrown into the air by volcanoes contains much dust which is carried long distances by air currents The northwestern part of this country was once a region of great volcanic activity, and deposits of volcanic dust are found in Idaho, Washington, Colorado, Oregon, Kansas, Wyoming, Nebraska, and Montana. It is from 4 to 30 feet in thickness in parts of Nebraska and much deeper in other states.

THE FORMATION OF THE SOIL

The production of soil material from rocks by weathering and the means by which these materials reached their present location have been discussed. At length the lower forms of plant life made their appearance and were in turn followed by higher plants

[1] COFFEY, G. N., Clay Dunes, *Jour. Geol.* Vol. 17, p. 754, 1909.

and animals. Plant material, or *organic matter*, by means of the work of soil organisms (Chap. III) set up additional chemical reactions in the soil material by which it was further modified—reactions that helped to render mineral nutrients available to other plants. After some organic matter had accumulated in the soil material, it may be said to have developed into *soil*. And after soil was formed, weathering and soil building went on as ever-continuing soil processes.

The Development of the Soil Section, or Profile.—For present purposes, the term *surface soil* refers to the furrow slice of about 7 inches in thickness, and the *upper subsoil* to the material immediately below the surface. This layer, or horizon, is considerably weathered and contains varying proportions of organic matter. It serves plants as a source of nutrients and as a reservoir for moisture. Under favorable conditions, the roots of many plants permeate the upper subsoil. Below this stratum is the *lower subsoil*. This layer usually contains but little organic matter; consequently, the preparation of plant nutrients is not carried on very actively in this stratum. Plant roots, however, penetrate open lower subsoils to varying depths and thus draw upon them as a reservoir for water. In the Midwest, it may be preferable to refer to the part of the dark-colored zone that is below the surface, or plow soil, as the *subsurface soil* rather than to call this material upper subsoil. These strata from a functional standpoint correspond only in a very general way to the *horizons*, a term that has come into general use. The horizons that constitute the soil section, or *profile*, have been designated *A*, *B*, and *C*. The *A* horizon is the topsoil from which material is being removed by leaching. Much of the organic matter in the soil is in this horizon. Immediately below the *A* is the *B* horizon. It receives the material that leaches from the *A* horizon and, therefore, may differ materially from it. Soil development is definitely in progress in the zone represented by the *A* and *B* horizons. The *C* horizon, which lies below the *B*, consists of unconsolidated material, usually referred to as the parent material. The upper part of it may be more or less weathered.

In humid areas, not only does rain water aid in the physical and chemical breakdown of the soil material, but it carries soluble materials from the surface and upper subsoil into the lower subsoil. In the event of continued heavy rainfall these

materials are carried out of the soil in drainage. Under some conditions, however, these soluble materials may accumulate in the subsoil. Thus the development of layers, or horizons, in the soil takes place (Fig. 17). In addition, some of the finer particles including colloidal material are carried downward and may be deposited at the approximate depth to which percolation goes from ordinary rains. After this deposition has partly filled the

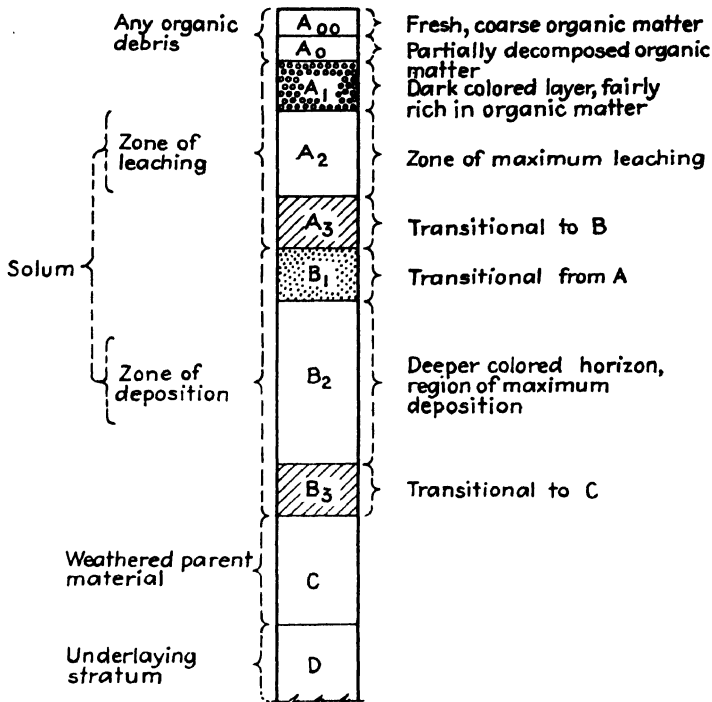



FIG. 17.—Hypothetical complete forest soil profile. Seldom does any soil have this complete profile although much of it is found in many profiles. (*After Kellogg.*)

pores, more and more materials tend to be trapped and held in this zone. Thus the subsoil horizons receive materials from above, and increasing differences between the surface and the lower layers are brought about. In other places, however, a highly compacted stratum has developed that may contain little colloidal matter.

In time, plant materials called "organic matter" accumulate in the surface soil and in places to varying depths in the upper

subsoil. The effect of organic matter on the color of the surface soil varies markedly with the climate, the condition of the soil, and the type of decay of the organic matter itself.

This brief outline suggests the mode of development of the layers or horizons that constitute the soil section, or profile, in humid areas.

In areas of lower rainfall, obviously less downward movement of both soluble materials and fine particles occurs. The reaction of the soil is less likely to be acid, and soluble substances are likely to be present in abundance. Under these conditions, the decomposition of organic matter and the color imparted to soils by it differ from those in humid areas. Moreover, arid and semiarid regions, for all these reasons, may be expected to have profiles that are less well developed and quite different from those of humid areas.

Soil and Plant Relationships.—The relationship of soils to plants may now receive consideration. In order to make satisfactory growth, crops require favorable conditions. Among these are a continuous supply of water, plant nutrients, heat, light, air, and a foothold, or anchorage, in the soil. The soil is concerned in some measure with supplying all these requirements for plant growth except light.

In his management of the soil, the farmer may do much toward the regulation of the supply of water that is readily available to crops. After rain falls, the farmer can remove any excess by drainage. Moreover, he can do something to keep the soil loose and open, in order that it may absorb and store water. By proper management, the tiller of the soil may reduce the losses of water to the advantage of crops.

Seeds require oxygen from the air for germination, and roots need it for growth. Plowing, seedbed preparation, and cultivation aid in the interchange of air between the soil and the atmosphere and thus supply oxygen needed by crops.

One of the important functions of the soil is that of supplying crops with plant nutrients. It is now recognized that plants require 14 elements for growth. These elements are carbon, oxygen, hydrogen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, boron, zinc, and copper. Only recently have the last four been recognized as elements required by plants.

As plants grow naturally on the soil, their tissues, except when eaten by the lower animals or harvested by man, fall back on the soil. Through the processes of decay, the nutrients in these tissues are made available to other plants. Moreover, the products of decay aid in rendering nutrients from the mineral soil materials available to plants. In addition, many tillage operations influence favorably the availability of the plant nutrients that are held in the soil.

If all the foregoing crop requirements are provided and if the soil has sufficient depth and desirable drainage, crop plants will develop a widespread root system that will make full use of the soil for the purpose of foothold.

Questions

1. What is meant by the weathering of rocks? Name the agencies of weathering, and show how each functions.

2. Discuss the important factors that affect the rate of weathering of rocks.

3. Discuss the importance of sedentary soil materials.

4. Distinguish between the more important groups of transported soil materials.

5. In what parts of the United States is each of these materials found?

6. Discuss the effect of velocity on (*a*) the weight of individual particles carried and (*b*) the total transporting power of streams.

7. Distinguish between soil materials and soils.

8. Discuss the development of the soil profile.

9. State the requirements for the growth of crops, and name the elements that plants require for growth.

10. To what extent can the farmer manage soils for the benefit of crops?

CHAPTER II

THE PHYSICAL PROPERTIES OF SOILS

A knowledge of the physical properties of soils constitutes the factual background upon which are based many of the operations involved in the practical management of soils in the field. An understanding of the significance of certain properties, such as color and texture, may be an invaluable aid in reaching a decision as to which of several parcels of land is likely to be most productive and hence most profitable for a prospective farmer to acquire. In the case of certain soils, their properties actually determine the practices that must be followed in order that crops may be grown successfully on them.

Color.—The color is probably the first property of the soil noted as one observes it. A young soil formed, as in arid climates, mainly by disintegration of rocks often has a color similar to that of the parent rock. A soil formed following feeble glaciation of a black shale that has undergone but little weathering is dark in color in accordance with the proportion of shale present. Similarly, dark-gray to black sands impart a dark color to soils of which they constitute a considerable proportion. The color produced by such shale, or sand, unless its significance is understood, may be decidedly misleading. Soil material produced by the glaciation of a red sandstone without admixture of much foreign material partakes of the characteristic color of the parent rock.

In addition to the mineral material itself, two substances, iron compounds and organic matter, determine the color of soils in the main. The physical and the chemical condition both of the iron compounds and of the organic matter markedly influence their effect on the color of the soil.

Iron Compounds.—In the weathering of iron-bearing rocks, the ultimate, or stable, form of this element is one of the oxides. A fair proportion of iron in a soil in the form of ferric oxide as hematite tends to give the soil a red or reddish color. The depth,

or shade, of red depends on the proportion of hematite and on the presence of organic matter or other substances capable of masking or diluting the red color. In relatively cool, humid climates, soils that contain appreciable quantities of iron compounds of the limonite groups tend to be yellow or yellowish in color. Again, the presence of organic matter or of other coloring substances influences markedly the color of the soil.

In the humid glaciated area of this country, the limonite group strongly influences the color of moderately well-drained soils. Southward of the glacial boundary, the upper subsoils and in places the lower subsoils vary from yellow to reddish yellow, yellowish red, and red particularly in the Piedmont.

Organic Matter.—Along with iron compounds, organic matter influences the color of soils to an important degree. The humid prairie soils of the Midwest are well supplied with organic matter and in color are dark brown to black. Within the limits of the prairie area in a general way, the depth of color may be taken as indicating roughly the proportion of organic matter in the surface soil. These dark colors[1] of the well-drained prairie soils are associated with a type of decomposition of the organic matter that is influenced by calcium. The darker shades give way to light browns, grays, and yellowish grays, particularly in forested soils.

Significance of Color in Subsoils.—In place of the yellowish color in the subsoil of many well-drained, humid, northern soils, this stratum in poorly drained, swampy, or permanently wet soils is characteristically gray or bluish gray in color. It has been suggested that the iron in these poorly drained subsoils occurs in the ferrous (FeO) condition.

Poorly drained and slow-draining subsoils in the humid northern and northeastern parts of the United States are characteristically gray or bluish or yellowish gray in color. The gray is often mottled with yellowish or rust-brown blotches or soft concretions of iron compounds. These colors of the suboil in the humid-climate area indicate lack of free drainage through the soil. The normally well-drained soil in this section of the United States has a yellow or yellowish-colored lower subsoil. Some loessal soils of the Midwest are slightly mottled with yellowish

[1] Browns and dark browns are associated with good drainage through the soil, and a black color with permanent or intermittent swamp conditions, either past or present.

gray but still may be rated as well drained. In the examination of soils for determining their adaptability for crops that require quick drainage, full examination and thorough consideration of the color and the consistency of the subsoil are of first importance. Similar investigation of the soil is essential for those who contemplate the purchase of land.

The Physical Composition of Soils.—Much attention is paid to the separation of soils into numerous grades or sizes of particles, often called "separates." The making of the separations is called *physical* or *mechanical analysis.* As with other sciences, classification is an essential phase of soil science.

In order that soil workers as well as farmers might have a basis of understanding, the adoption of soil-particle-size classifications was essential. Various workers established classifications, many of which are no longer in use. But they pointed the way to the better currently used classifications.

The Size of Soil Particles.—The sizes of soil particles used in the United States today are those of the U.S. Department of Agriculture. The diameter limits of these particles are given in Table 1.

Table 1.—Classification of Size of Soil Particles*

Name of Soil Particles of Different Sizes	Diameter, Millimeters
Fine gravel	2.00–1.0
Coarse sand	1.00–0.5
Medium sand	0.50–0.25
Fine sand	0.25–0.10
Very fine sand	0.10–0.05
Silt	0.05–0.002
Clay	Less than 0.002

* Classification used by the Bureau of Chemistry and Soils, U.S. Department of Agriculture, since 1938.

Note: The coarser particles such as the gravel and the four sizes of sands may be separated by means of sieves, the different separates weighed, and their percentage of the sample calculated. The finer particles may be separated in accordance with their rate of settling in water. Further information is available in A Pipette Method of Mechanical Analysis of Soils Based on Improved Dispersion Procedure, by L. B. Olmstead, L. T. Alexander, and H. E. Middleton, *U.S. Dept. Agr., Tech. Bull.* 170, 1930.

The term *texture* is used with reference to the size, but not to the arrangement, of soil particles. Soils in which sand predominates are referred to as "coarse-textured" soils. Those in which the finer silt and clay dominate the physical properties are called "fine-textured" soils. The intermediate ones that contain

some clay, much silt, and considerable very fine sand may be designated as "medium-textured" soils. As will be emphasized later, medium-textured soils possess definite advantages over both the coarse- and the fine-textured ones.

Soil Classes Based on Texture.—Representative soil classes may now be introduced, the coarse-textured ones being given first.

Soil class	Characteristics
Gravel Gravelly loam Sandy gravelly loam Sand Loamy sand	Coarse-textured soil classes Dry, early soils
Loam Silt loam	Medium-textured soil classes Intermediate, highly desirable soils
Clayey silt loam Silty clay loam Clay loam Clay	Fine-textured soil classes Moisture-retentive. May be cold late soils

In loam, many particle sizes are represented, but none of them dominates its characteristics. Enough sand, often fine and medium, is present to give a gritty feeling and clay enough to make a loam slightly plastic when moist. Much silt is present,

(a) (b) (c)

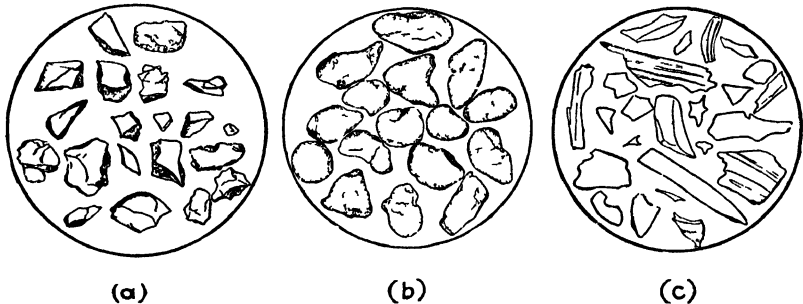



FIG 18 -Shapes of soil particles *a*, angular particles in a residual soil *b*, quartz particles of beach sand that were rounded by wave action. Streams round off the angles of particles of sand and gravel in a similar manner. *c*, outlines of particles of volcanic dust as seen under the microscope. (*From G. P Merrill, "Rocks, Rock-weathering, and Soils." By permission of The Macmillan Company, publishers.*)

and this modifies the physical characteristics usually imparted by sands on the one hand and by clay on the other. Loams are highly desirable soils. The names of the various other soil classes are descriptive and, therefore, indicate the characteristics that may be expected in each of these soil classes.

The Shape of Particles.—Great variety exists in the shape of soil particles. Those which were produced by the action of streams, winds, glaciers, and waves tend to be rounded or spherical. Residual materials tend to be angular because they have not been worn or otherwise affected by transporting agencies, Clay particles, or at least some of them, possess shapes in the form of sheets or plates that are entirely unlike those of the larger particles. Volcanic ash materials which were produced in part by explosions are most irregular in shape (Fig. 18). Because of the shape of the particles, some volcanic-ash soils are decidedly loose and open.

The Number of Particles.—The number of soil particles in a given volume or weight may be largely a matter of academic interest. Obviously, 1 pound of coarse sand contains fewer particles than does 1 pound of a fine silt. Clearly, it is impossible to calculate the exact number of particles in a soil. Information of interest, however, may be obtained by using the average diameter of the particles in each size group in such calculations.

The Internal Surface of Soils.—The total surface of all of the particles in a given weight of soil is its internal surface. Because the internal surface of the soil affects many relationships between soils and plants, it merits attention. Internal surface may be expressed in square feet or in acres per pound or per cubic foot of soil.

Taking the mechanical analysis of soils and using the average diameter of the particles of each size group and assuming the soil particles to be spherical, one can calculate their approximate internal surface. This has been done and the resulting data are presented in Table 2.

With the exception of the drab clay which was deposited by evaporation in shallow water on an alluvial flood plain, the soil materials in Table 2 were placed by the wind. The black clay loam, however, has been influenced by the assorting action of water. The sand in the dune sand and the brown sandy loam is mainly fine, with an admixture of medium sand. The great extent of surface in the drab clay indicates a high percentage of fine clay in its make-up. Had its colloidal (page 32) content been considered, the internal surface would have been much greater.

On the basis of the brown silt loam with an internal surface 1.6 acres per cubic foot, corn hills planted 42 inches apart each

TABLE 2.—INTERNAL SURFACE OF SOILS CALCULATED FROM THEIR MECHANICAL ANALYSES*

Soils	Internal surface per cubic foot	
	Square feet	Acres
Dune sand	30,310	0.696
Brown sandy loam (prairie)	55,380	1.271
Yellow-gray silt loam (timber)	69,780	1.602
Brown silt loam (prairie)	70,900	1.628
Black clay loam (prairie)	81,780	1.877
Drab clay (often timbered)	136,700	3.138

* MOSIER, J. G., and A. F. GUSTAFSON, "Soil Physics and Management," J. B. Lippincott Company, Philadelphia, 1917.

way have almost 80 acres of soil-particle surface to a depth of 4 feet from which to draw moisture and plant nutrients for their growth. This distance of planting is common in the central and southern parts of the Corn Belt; 36 inches is usual in the northern part. If we calculate for the latter spacing to a depth of 3 feet, each hill of corn has 44 acres of soil surface to serve its needs. The function of internal surface receives further consideration in the discussion of colloids (page 32) and soil moisture (page 82).

Properties of Sands.—Sands are coarse. Sandy soils have large pores, but relatively low total porosity, and little total internal surface. As a result of their large pores, sandy and gravelly soils drain so freely as to be distinctly droughty. For the same reason, aeration takes place so freely that organic matter in them "burns out" readily. Moreover, sands are loose and incoherent, and tillage, therefore, is accomplished easily, or with light draft. As a result, farmers have thought of sands as "light" soils, although they are heavy in actual weight.

Properties of Silt.—Silt particles are intermediate in size and in comparison with sands have a relatively large internal surface. In contrast with the finer separates, however, silt has a small internal surface. Field soils that are composed largely of silt particles have pores large enough for satisfactory drainage and exchange of air. The pores are of a size that enables silty soils to retain moisture to a desirable extent and at the same time to deliver it to plants. In the field, silt is almost universally accom-

panied by a desirable admixture of finer particles. This mixture of particles possesses properties that are almost ideal from the physical standpoint for the production of many crops. It should be pointed out, however, that silt loams, particularly if low in organic matter, become compacted easily.

Properties of Clay—Colloids.—The upper limit in size of clay as used by the U. S. Department of Agriculture is 0.002 millimeter in diameter. Marshall[1] uses 0.001 millimeter. Particles of matter smaller than 0.001 millimeter according to Marshall exhibit distinct colloidal properties. Colloidal materials are of two classes, mineral and organic. Although they are entirely different in constitution, the two classes have many properties in common. It should be stated, however, that a fine distinction between their effects on soils is not attempted here.

Anderson and Mattson[2] calculated the average size of the colloidal particles in soils as ranging from 91 to 141 millimicrons or 0.000091 to 0.000141 millimeter, in diameter. The data are given in Table 3.

TABLE 3.—SIZE, NUMBER, AND INTERNAL SURFACE OF COLLOIDAL SOIL PARTICLES*

Soil Series U.S.D.A.	Average diameter of particles, millimicrons	Number of particles per gram of colloid particles	Total surface per gram of colloid particles, square meters	Total surface per cubic foot (80 lb.) of colloid particles,† acres
Susquehanna..	141	263,000,000,000,000	15.7	146.6
Norfolk.......	129	322,000,000,000,000	17.1	153.6
Sassafras......	128	335,000,000,000,000	17.0	152.2
Huntington...	111	505,000,000,000,000	20.4	182.7
Marshall......	106	613,000,000,000,000	21.5	192.5
Sharkey......	91	960,000,000,000,000	24.2	216.7
Fallon........	102	680,000,000,000,000	21.3	190.7

* ANDERSON, M. S., and SANTE MATTSON, Properties of Colloidal Soil Material, *U.S. Dept. Agr., Bull.* 1452, p. 4, 1926.

† Last column calculated and added by the author.

[1] MARSHALL, C. E., "Colloids in Agriculture," p. 6, Edward Arnold & Co., London, 1935. A popular discussion is given in this book.

[2] ANDERSON, M. S., and SANTE MATTSON, Properties of the Colloidal Soil Material, *U.S. Dept. Agr., Bull.* 1452, p. 4, 1926.

It is interesting to note that the size of a medium, average-sized colloidal soil particle (Fallon, Table 3) is 1/10,000 that of the upper-limit sand particle, 1 millimeter in diameter; or, putting it another way, 10,000 of these colloidal particles laid so as to touch each other would give a length equal to the diameter of a large grain of sand. If the average-sized colloidal particle is represented by a marble of approximately 0.66 inch in diameter, a large sand grain would be represented by 550 feet, the height of the Washington monument. In other words, the size of the smaller colloidal particles indeed is infinitesimal. The number of particles in a gram of colloidal soil material is so great as to be all but beyond comprehension (see Table 3).

The internal surface in acres, given in the final column of Table 3, was calculated by the author to show its true magnitude. One cubic foot of coarse sand, for instance, has an internal surface of only 0.027 acre in comparison with more than 216 acres for 1 cubic foot of average colloidal material from the Sharkey soil. The shape of colloidal particles has a great influence on internal surface. The fact of importance, however, is the immense surface exposed by colloidal matter.

In addition, colloidal particles carry an electrical charge, possess hydrogen-ion concentration (page 228) similar to that of other soil materials, act as a reservoir for the ions of various plant nutrients, and govern plasticity, tenacity, shrinkage, and puddling of soils. Moreover, because of the large internal surface of colloidal material, it may be regarded in a sense as the key to the chemical and biological activities in the soil.

Plasticity.—Soils that possess the property of plasticity owe it largely if not entirely to the mineral colloidal matter present. A plastic soil is one which, given the right amount of water, may be modeled or shaped at will. Sands and silts without colloidal matter possess no plasticity. As increasing amounts of water are added to heavy soils, they become more sticky and plastic up to the point of maximum plasticity. After that, additional water eventually produces a thin suspension, and satisfactory measurement of plasticity in definite units is difficult. The plasticity of soils is a useful criterion for estimating their colloidal content. The soil surveyor depends on the degree of plasticity for determining the boundaries between the heavier soil types. The shape and structure along with the size of particles influence plasticity and tenacity.

Tenacity.—Tenacity is resistance to rupture or separation of particles and, therefore, is the quality that imparts stability to soils. When they are dry, tenacious soils possess a high degree of cohesion. In mineral soils, this property results primarily from the presence of colloidal matter and water. As with plasticity, excessive quantities of water destroy tenacity.

FIG. 10. Shrinkage in black clay loam in Illinois. This soil is well supplied with organic matter and contains some colloidal clay. Upon evaporation of water from the soil, the particles are drawn together and cracks such as this result.

Much power is required to pull plows or other tillage implements through highly tenacious soils. Owing to the "heavy" draft of tillage implements, farmers have come to call tenacious soils "heavy" ones. These soils under favorable conditions, however, may be light in actual weight. Clays low in organic content and high in colloids are most tenacious and are followed,

in turn, by clay loams, silty clay loams, and clayey silt loams. Silty soils are so low in colloidal matter as to have little tenacity.

Shrinkage.—As stated on page 33, soil colloids may be expected to undergo marked expansion upon wetting. The opposite, namely, that wet soils containing appreciable quantities of colloidal matter shrink upon drying, is to be expected. Precisely these changes occur in the field and are markedly accentuated by high proportions of organic and mineral colloids.

Fig. 20.—Shrinkage in coarse-, medium-, and fine-grained soils and peat. As the organic and clay content of these soils increases, so also does the shrinkage as would be expected.

A moderate rain may saturate the surface soil completely, so that because of swelling the surface is free from cracks. In a saturated soil, the pore space is filled with water. As loss of water by evaporation proceeds, the particles, which had been pushed apart by swelling as they became wet, are now brought together by the force of cohesion. Shrinkage, therefore, is in progress. Repeated wetting and drying, or the accompanying swelling and shrinking, aid in bringing about the highly desirable condition of the soil that results from granulation.

Though shrinkage is helpful from the standpoint of the immediate surface effects, called "granulation," deep shrinkage cracks during long dry periods may be harmful to crops. Plants are

injured by the breaking off of roots and the loss of water. The author has observed cracks 2 inches in width in a highly colloidal gray clay. In this soil, the cracks extended to a depth of less than 10 inches. In dark-colored clay loams and silt loams, the cracks extend to depths of 2 to 3 feet, or about 60 centimeters to 1 meter and even more, during prolonged droughts. Figure 19 shows such a shrinkage crack in black clay loam in Illinois.

In order to study the behavior of a series of soils that varied in colloidal and organic content, they were thoroughly wetted and then dried. The reduction in area or the shrinkage brought about by drying was measured. The soils were photographed and are shown in Fig. 20. The percentages of total organic matter, moisture, and areal shrinkage in these and two additional soils are given in Table 4.

TABLE 4.—SHRINKAGE OF SOILS OF VARIED COLLOIDAL AND ORGANIC CONTENT*

Soils	Organic content, per cent	Moisture, per cent	Total shrinkage, per cent
1. Sand	0.75	9.67	1.88
2. Yellow find sandy loam	0.80	21.39	2.48
3. Brown sandy loam	2.90	17.43	4.94
4. White silt loam	0.79	23.69	4.11
5. Brown silt loam	4.88	31.93	10.26
6. Black clay loam	5.50	40.83	19.00
7. Drab clay	3.60	61.94	31.93
8. Peaty soil	64.40	193.94	32.64

* MOSIER, J. G., and A. F. GUSTAFSON, "Soil Physics and Management," p. 135, J. B. Lippincott Company, Philadelphia, 1917.

Some observations of interest may be made on these data. Shrinkage is slight in the soils (1, 2, and 4, Table 4) of low colloidal and organic content. It is organic and not colloidal matter that caused the shrinkage in the brown sandy loam. The variation in shrinkage between the brown silt loam and the black clay loam is caused by the higher colloidal content of the latter. Between the black clay loam and the drab clay the difference is caused by the high colloidal content of the drab clay.

Flocculation and Puddling. If a dry clayey soil is finely ground or if a wet one is rubbed as with a pestle in a mortar, much of its

colloidal material is released from the natural lumps, crumbs, or granules. If placed in water, the colloidal particles remain in suspension for many days. The addition of calcium hydroxide, hydrochloric acid, common salt, or similar material produces a grouping of the clay particles into floccules, or brings about flocculation. This action explains the clear condition of water in streams, ponds, and lakes in areas where the surface or the ground water acquires soluble calcium.

Many heavy soils are naturally in good physical condition, but this may be destroyed by improper management. The term *puddling* has been applied to the breaking down of the granules in the soil. Permitting livestock to trample wet, thawed-out, heavy soils or hauling manure over soft soils in late winter or early spring destroys the granules and brings about puddling. Plowing heavy soils when wet is almost certain to cause puddling. Once soils are puddled badly, it may require several seasons to restore them to good tilth; organic matter is distinctly advantageous for producing good tilth.

The Chemical Activity of Colloids.—On the basis of the studies of colloidal chemistry carried on during the past two decades, it is now known that factors other than solubility come into play. One factor is the enormous amount of internal surface exposed by colloidal matter.

Colloids are now regarded as having a negatively charged interior about which are swarms of positive ions (cations). The ions are more or less attached to the colloidal particles; yet they are relatively free to exchange places with other cations. Water is present in and about the colloidal matter to such an extent that some of the materials present may be practically in soluble form. Certainly they are highly mobile and almost instantly reactive. The positive ions on the surface may easily be exchanged for others by the process of *ionic*, or *base, exchange.* Hydrogen ions are represented by H^+ and calcium by Ca^{++}. Hydrogen and calcium ions are most active. As hydrogen ions displace calcium ions in the colloidal material, the latter by loss of calcium tends to become acid. From the foregoing, it may be inferred that colloidal material acts much as do ordinary salts in many respects. Potassium, K^+, from fertilizers or manures may enter the colloidal complex in the same manner as does H^+ and may displace Ca^{++} which is lost in soluble form from the soil.

From this outline, it may be inferred that colloidal materials are exceedingly active in the soil and that mineral and organic colloidal materials constitute a very valuable part of arable soils.

Structure of the Soil.—The term *texture* (page 28) indicates the make-up of soils from the standpoint of the percentage of the different-sized particles. *Structure* is the term used to indicate the condition of a soil with respect to the aggregation of the soil particles. Sands have a single-grain structure, but this is not objectionable or detrimental in the coarser soils. In the finer soils, single-grain structure is most undesirable because the pores are so small as to permit only very slow drainage. Likewise, detrimental gases cannot readily get out or fresh air in.

The desirable condition in heavy soils is that of a crumb structure, or granular condition. As previously indicated, this condition is brought about by nature in soils sufficiently supplied with organic and mineral colloidal matter. In the absence of the organic colloids, it is doubtful if satisfactory granulation is likely to take place. The soils that have a granular structure till more easily, drain more quickly, undergo more rapid and complete aeration, and produce better growth of crops than do those of less desirable structure.

Tight Clay, Hardpan, Plow Sole.—For lack of a better place, these three special soil conditions are discussed at this point.

The term *tight clay* is a broad, general one used to indicate a condition of unusually slow drainage through the subsoil. Mineral colloids that have been carried downward by percolation may be responsible in part for this undesirable condition. The tight-clay layer usually occupies a position that suggests its deposition by percolating water. The term tight clay is applied also to a stratum of very compact silt that practically prevents percolation. This layer occurs at varying depths. Its location may result from differences in the rate of percolation through the overlying soil. Moreover, in places the original surface soil has been removed by erosion, and the tight clay occurs as the present surface material. Various names, such as "scald spots" and "slick spots," are applied to tight or compact subsoil that is thus exposed on the surface or which lies only a short distance below the surface. In any event, the presence of a slow-draining layer is exceedingly detrimental to crops during periods of either excessive or deficient rainfall. With excessive rainfall, crops are

drowned and with deficient precipitation, the crop is injured by drought because of shallow rooting and no appreciable upward movement of water through the tight layer.

The term *hardpan* is often used synonymously with tight clay, but should refer to another condition. In places the soil material is cemented together producing an impervious condition. Whatever the cementing agent, this condition is referred to as hardpan.

If soils are plowed at the identical depth year after year, particularly if heavy ones are turned while somewhat too wet, a more or less compact layer, which may sometimes be partly puddled, develops on the bottom of the furrow. The dragging or sliding of the plow because of the pressure it exerts, particularly in the case of a walking plow, materially packs the bottom of the furrow. The more or less impervious condition so developed is referred to as the *plow pan* or the *plow sole.*

The remedy for this undesirable condition is to vary the depth of plowing from year to year and to avoid plowing if the soil is moist enough to puddle.

Weight of Soils.—In common with other substances, soils obviously possess weight. It is necessary to know their weight in order to calculate the percentage of moisture, organic matter, and plant nutrients in soils. The weight of soil is determined by that of its constituents and by the arrangement or mode of packing of the soil particles.

Specific Gravity.—The specific gravity[1] of important soil-forming minerals has been determined. That of quartz is 2.65; of calcite, 2.70; of dolomite, 2.85; of orthoclase, 2.56; of limonite, 3.6 to 4.0; of hematite, 4.5 to 5.3; of mica, 2.7 to 3.1; and of soil organic matter 1.2 to 1.3. Each constituent contributes its proportionate share to the specific gravity of the soil as a whole.

The specific gravity of black clay loam, as mapped in Illinois, was 2.57; of a well-drained, prairie, brown silt loam, 2.62; and of several timbered silt loams, 2.65.[2] The black clay loam contains

[1] Specific gravity of soils is determined by the displacement of water in a picnometer. All weights are obtained in grams.

$$\frac{\text{Weight of water-free soil (grams)}}{\text{Weight of water displaced by soil (grams)}} = \text{specific gravity of the soil}$$

[2] Mosier, J. G., and A. F. Gustafson, "Soil Physics and Management," p. 175, J. B. Lippincott Company, Philadelphia, 1917.

the highest and the timbered soils the lowest percentage of organic matter, and the specific gravity of these soils varies accordingly. Obviously, because of its own relatively low specific gravity, organic matter has a marked influence on the specific gravity of soils.

Volume Weight.—Field soils are never solid like a piece of stone but, instead, contain much space that is occupied by air and water. Because of the inconvenience of weighing large quantities of soil, such as an acre-foot,[1] the volume weight[2] is determined. The weight of any desired quantity of soil may then be calculated.

The difference between the specific gravity and the volume weight of soils may be stated in this way. In determining specific gravity the volume of actual soil material is found by displacement in water. The air or the unoccupied space in the soil is thus completely eliminated. In the determination of volume weight, however, air or pore space is included in the volume. Volume weight, therefore, is represented by a lower figure than that for specific gravity.

Great variation exists between the volume weight of different soils and that of the same soil under different conditions. For this there are a number of causes. The volume weight is influenced markedly by the arrangement or mode of packing of the soil particles or granules. If the openings between the particles are large in one soil and small in another without great difference in the number of openings, the soil with the smaller openings will contain a higher proportion of solid material and, therefore, will have the higher volume weight. Minor influences are exerted by the specific gravity of the soil material and by the percentage of

[1] One acre-foot of soil is the soil over an acre to a depth of 1 foot. One acre-inch of soil or water is the soil or water over an acre to the depth of 1 inch.

[2] Volume weight of soils may be determined in a number of ways. In all of them, the field volume of soil is measured and the soil itself reduced to a water-free condition in a drying oven. It is then cooled and weighed. Cubic centimeters and grams are convenient units for the measurements. Volume weight may then be calculated.

$$\text{Volume weight} = \frac{\text{weight of water-free soil (grams)}}{\text{volume of soil (cubic centimeters)}}$$

If the weight of the water-free soil is 128.2 grams and its volume 100 cubic centimeters, its volume weight is 1.282. In other words, the volume weight is the weight in grams of 1 cubic centimeter of dry soil including pore space.

organic matter (specific gravity 1.2 to 1.3) in the soil. Decomposed organic matter, however, because of its granulating influence on heavy soils may have a marked effect in the direction of lowering the volume weight of soils. And because irregularly shaped particles do not fit together closely, such particles are likely to give a lower volume weight than do rounded particles which may fit together without large openings between them.

In sands, the individual particles are relatively free to assume a position of close packing. With this arrangement of particles, the unoccupied space is low, and sands, therefore, have a relatively high volume weight. Sands and sandy loams vary in volume weight from 1.35 to 1.75.

TABLE 5.—VOLUME WEIGHTS OF SOIL TYPES IN ILLINOIS*

Soil types	Horizon or stratum			
	A_1 horizon		B_1 horizon	
	Volume weight	Pounds per cubic foot	Depth, inches	Volume weight
1. Tama silt loam (brown, prairie)†	1.28	79.90†	18–27.5	1.32
2. Muscatine silt loam (brown, prairie)	1.20	74.90	19–29	1.32
3. Muscatine silt loam (brown, prairie)	1.28	79.90		1.36
4. Grundy silt loam (brown, prairie)	1.24	77.40	15.5–25	1.31
5. Black clay loam (black, prairie)	1.28	79.90	20–31	1.35
6. Brown sandy loam (prairie)	1.49	93.00	19–32	1.45
7. Edina silt loam (grayish brown, prairie)	1.22	76.15	19–29.5	1.32
8. Clinton silt loam (yellowish gray, timber)	1.46	91.13	17–28	1.46
9. Gray silt loam on tight clay (timber)	1.51	94.25	15.5–27.5	1.51
10. Yellow gray silt loam on tight clay (timber)	1.62	101.12	17–27	1.49

* HARLAND, M. B., and R. S. SMITH, Volume Weight of Certain Field Soils, *Jour. Amer. Soc. Agron.*, Vol. 20, p. 537, 1928 (see this paper for a discussion of methods of determining volume weight).

† Added by the author.

In silt loams and clay loams, the arrangement of the particles is of utmost importance. Since the individual particles in these soils are small and light, they tend to assume a relationship to each other that is somewhat similar to the theoretical vertical arrangement. In a broad sense, this is the arrangement of particles, granules, and clods, immediately after a silt loam in good tilth has been plowed. In this condition, its volume weight may be as low as 1.1 or even less. As the season progresses, rainfall, gravity, and tillage close the larger openings between the clods and bring the granules and particles closer together. During this adjustment, the volume weight gradually rises and may reach 1.5 by the following spring. Volume weight, therefore, may be used in a general way as a measure of the physical condition, or tilth, of soils. Silt loams, clay loams, and other heavy soils vary in volume weight from 1.1 to more than 1.6. Harland and Smith have given the volume weight of a number of virgin Illinois soils that represent these types in a general way. The data are given in Table 5.

The difference in volume weights of these soils with the exception of the brown sandy loam (6 in the table) is caused by the influence of the organic matter on their physical condition. The brown sandy loam is relatively higher in volume weight than the brown silt loams because of its coarser texture.

When the volume weight of a soil is determined, finding the weight of any desired quantity of it is a matter of simple calculation.[1]

The weight of 1 cubic foot of a soil (volume weight 1.28) is approximately 80 pounds. For various calculations, it is necessary to know the weight of soils to plow depth, or about 6½ to 7 inches over an acre. The soil under consideration weighs 2,033,370 pounds over an acre to the depth of 7 inches. For silt loams,

[1] 62.42 pounds = weight of 1 cubic foot of water (62.43 lb. at 4°C.)
1.282 = volume weight of soil under consideration
43,560 square feet = 1 acre
Assumed approximate plow depth = 7 inches
62.42 × 43,560 = 2,719,015 pounds = 1 acre-foot of water
2,719,015 ÷ 12 = 226,584 (or 113¼ tons) = 1 acre-inch of water
62.42 × 1.282 = 80.02—weight of 1 cubic foot of this soil
80.02 × 43,560 = 3,485,777 pounds = weight of 1 acre-foot
3,485,777 ÷ 12 (inches) × 7 (inches) = 2,033,370 pounds—the weight of soil to plow depth over 1 acre

clay loams, and clays, 2,000,000 pounds (1,000 tons) is a satisfactory figure for general use as the dry weight of an acre 7 inches of soil. As indicated in Table 5, sandy soils are heavier than the silty and clayey ones of similar organic content. Soils 9 and 10 (Table 5) are low in organic matter and become compact. It should be appreciated that silt and clay loams and clays may become very compact over winter or in late summer especially in humid climates or under irrigation. In this state, their volume weight and actual weight per cubic foot are very high, in fact, may be higher than that of sand. Under comparable conditions, however, sands usually are heavier per unit volume than the finer grained soils. A weight of 2,500,000 pounds (1,250 tons) is suitable for general conditions involving sandy and gravelly loams and sands.

In subsoils, a different condition with respect to volume weight is often encountered. Bradfield and Jamison[1] found the subsoil of Miami silty clay loam to have a volume weight of 2.1 and a porosity that is correspondingly low—22 per cent. In a stratum in this physical condition, as would be expected, drainage and aeration are essentially absent.

Porosity of Mineral Soils.—From the foregoing discussion, the interrelationship between the volume weight and the porosity[2] of soils must be evident. Arable soils consist of solids, in the form of mineral particles and organic matter, and of pore space that is occupied by water (liquid) and air (gases). Soils, therefore, consist of matter in its three phases—solids, liquids, and gases. The actual solids as such do not vary materially; yet the proportion of solids to liquid and gases in soils under crops is constantly changing.

[1] BRADFIELD, RICHARD, and V. C. JAMISON, Soil Structure—Attempts at Its Quantitative Characterization, *Proc. Soil Science Soc. Amer.*, Vol. 3, pp. 70–76, 1938.

[2] Porosity, or percentage of pore space, in soil may be calculated readily from its specific gravity and volume weight. Porosity or per cent of pore space is calculated thus:

$$100 - \frac{\text{volume weight}}{\text{specific gravity}} \times \frac{100}{1}$$

or, substituting,

$$100 - \frac{1.282}{2.65} \times \frac{100}{1} = 51.6 \text{ per cent of pore space}$$

An ideal situation in an arable soil is for approximately one-half of its volume to be made up of solids and for the other half to be divided about equally between soil moisture and air. As a broad generalization, then, one-half of a soil is composed of mineral and organic matter, one-fourth, moisture, and the remaining fourth, gases.

As water is removed from the soil by plants or by evaporation, air is drawn in; and temporarily, therefore, more than one-fourth of the volume is gas, and correspondingly less than one-fourth is liquid. In contrast, much of the air may be expelled by water from heavy rains or irrigation, and more than one-fourth of the volume is then occupied by water. Drainage, evaporation, and crops, however, remove water and tend to restore the ideal situation between liquid and gases in the soil.

The size of the individual pores, rather than the percentage of total pore space in a soil, controls the rate of movement of water through, and of gases into and out of, the soil. The reason underlying the effect of the size of pores is that the rate of flow of liquids varies as the fourth power of the sizes of the openings. If the size of the pores is doubled, the quantity of water that passes through in a given time is multiplied by 16. This fact helps to explain the enormous difference in the rate of drainage through coarse as compared with fine-grained soils and the slow drainage through compact, fine-grained subsoils. In the finer grained soils, however, the pores are very irregular in shape, and this interferes with the movement of water through them.

Temperature of the Soil.—The growth of plants is markedly influenced by temperature. In the soil, the lower forms of plant life that are so vital to higher plants and animals are similarly affected by the temperature of the soil. Higher plants require a suitable temperature both of the soil and of the atmosphere.

Sources of Heat.—The sun is the ultimate source of the heat received by the soil. Physical phenomena and chemical reactions exert some slight influence on soil temperature, but solar radiation is the one important and direct source of heat for the soil.

Losses of Heat.—Soils lose heat in several ways, one of the most important of which is by radiation into the atmosphere. Loss of heat by soils appears to be independent of their color, as shown

by Bouyoucos[1] who found only slight differences in radiation in white sand as compared with black, blue, green, red, or yellow sand. The darker colored soils, however, take up heat in bright sunshine and, therefore, contain more heat in daytime. This is lost by radiation during the night. By morning, therefore, surface soils may be expected to have attained approximately uniform temperatures. Minor losses of heat take place by means of convection currents and by downward conduction into the soil.

Heavy losses of heat are brought about by evaporation of water from wet soils. Fortunately, these losses are subject to a measure of control by the farmer; they receive further consideration later in this chapter (page 50).

Temperatures Required for Germination and Growth.—The temperatures required by seeds for germination and by plants for growth are similar. Some seeds germinate and grow best at a medium temperature, others at a low one; and still others need a high temperature. Haberlandt in Germany determined the temperatures at which the seeds of a number of economic plants germinate. His data are given in Table 6.

TABLE 6.—TEMPERATURES OF SOIL FOR GERMINATION*
(Degrees Fahrenheit)

Crop seeds	Minimum	Optimum	Maximum
Peas, wheat, barley	32–40	77– 88	100
Corn (maize)	40–51	88–100	111–122
Red clover	32–40	77–100	100–111
Turnip	32 40	77– 88	88–100
Mustard	32–40	61 88	88–100
Melon	60–65	88–100	111–122
Pumpkin	51–60	100	111–122
Oats	32–40	77	88–100

* HABERLANDT, F., *Landw. Vers. Sta.*, Vol. 17, pp. 104–116, 1874.

From Table 6, it is clear that the crops studied fall into two general groups, particularly with respect to minimum and maximum temperatures for germination. Peas, wheat, barley, oats, mustard, turnip, and red clover are capable of germination at

[1] BOUYOUCOS, G. J., An Investigation of Soil Temperature and Some of the Most Important Factors Influencing It, *Michigan Agr. Exp. Sta., Tech. Bul.* 17, p. 30, 1913.

40°F. and lower; but corn, melons, and pumpkins require higher temperatures for germination.

Judging from other experimental work, rye and mustard are capable of making somewhat better growth at low temperatures than are barley, oats, and wheat. Hall determined the minimum, optimum, and maximum temperatures for the growth of certain crops. His data are given in Table 7.

TABLE 7.—TEMPERATURE OF SOIL REQUIRED FOR CROP GROWTH*
(Degrees Fahrenheit)

Crops	Minimum	Optimum	Maximum
Mustard	32	81.0	99.0
Barley	41	83.6	99.8
Wheat	41	83.6	108.5
Maize (corn)	49	93.6	115.0
Kidney bean	49	92.6	115.0
Melon	65	91.4	111.0

* HALL, A. D., "The Soil," p. 152, E. P. Dutton & Company, Inc., New York, 1931.

Though Hall's data for growth vary in detail somewhat from those of Haberlandt for germination, the similarity is striking. The farmer long since observed differences in the time and temperature at which the seeds of various crops germinate and adapted his practices accordingly. For example, he seeds oats early and corn, beans, and melons later in the planting season. If seeds that require high temperatures for germination are planted in cold soils, the seeds decay instead of germinating. Unseasonably cool wet periods sometimes follow the planting of corn. Because of the rotting of the seed, a second planting is sometimes necessary if even a fairly good stand is to be obtained.

Among feed crops, oats, peas, clover, and grasses are seeded relatively early in the spring throughout the sections of the country in which these crops are important. Barley may be seeded for some time after the regular oat-seeding period. Corn is planted later; soybeans, millet, and Sudan grass follow corn. Some care is taken, of course, not to plant frost-sensitive feed and vegetable crops such as corn, beans, soybeans, tomatoes, peppers, and others in cold soils or while there is danger of their being killed by frosts.

Fortunately, various physical processes in soils and plants take place and the work of beneficial soil organisms is done within the temperature range that is favorable for the growth of crops.

Conditions That Affect Soil Temperatures.—A number of conditions determine the temperature of the soil. Some of them may be controlled in a measure by the farmer, but others cannot be. By adapting crops to conditions, advantage may sometimes be taken even of the uncontrollable factors.

Slope of the Land.—Slope, or inclination, of the land is one of the more obvious factors that affect soil temperatures. A slope facing the sun during the hottest part of the day receives the most heat, and one facing exactly the opposite direction receives the least. Crops, such as apples, that are subject to scald from the heat of the sun should not be planted on south and southwest slopes in areas where temperatures often become high enough to cause trouble. Many pasture grasses cease growing at high temperatures; a cool north slope, therefore, is preferable to a south slope for midsummer pasture production in the warmer climates. Crops that are sensitive to frost such as peaches, certain nut trees, and black locust may well be kept off of hot south slopes lest they blossom or leaf out so early under the influence of the warm midday sun as to be injured later by frost.

Color of the Soil.—The color of soils exerts considerable influence on their temperature. As elsewhere, dark colors absorb more heat in sunshine than do lighter ones. Bouyoucos[1] found that staining white sand black raised its temperature in sunshine 11.34°F. (6.3°C.) in July and, in August, 10.62°F. (5.9°C.) at 2 and 2:30 P.M., respectively. The highest daily soil temperature is usually attained at about 2 P.M.

In the same field, under similar soil conditions, wheat germinates and grows more rapidly on dark-colored than on light-colored soil. After growth is well under way, it would be expected to be more rapid on the dark-colored soil, which yields more plant nutrients than does the light-colored one.

A similar situation has been noted in corn fields. The seed germinates and the plants come up sooner on the darker colored land. In fact, the rows can be followed with the eye several days earlier on the dark- than on the light-colored land, and these

[1] BOUYOUCOS, *op. cit.*, p. 31.

differences persist throughout the season owing to the higher organic and plant-nutrient content of the dark-colored soil.

This effect of color on temperature of the soil and on germination of seeds and growth of plants is shown in Tables 8 and 9.

TABLE 8.—EFFECT OF COLOR ON THE NUMBER OF PLANTS THAT CAME UP AND THE LENGTH OF TIME REQUIRED*
(100 Seeds of Each Planted)

Days after planting	Wheat		Oats		Corn		Melons	
	Light	Dark	Light	Dark	Light	Dark	Light	Dark
7	..	4	..	6				
8	8	75	..	80				
9	29	86	27	100	..	6		
10	51	86	70	100	1	84	..	21
11	58	86	75	100	66	95	4	60
12	62	86	75	100	72	95	32	86
13	65	86	75	100	72	95	57	86

* Demonstration conducted at the University of Illinois.

TABLE 9.—EFFECT OF COLOR OF SOIL ON ABSORPTION OF HEAT*

Time	Depth below surface of soil					
	1 in.		2 in.		4 in.	
	Light	Dark	Light	Dark	Light	Dark
	Degrees Fahrenheit					
6 A.M.	48.8	50.0	47.5	49.0	48.5	50.5
Maximum reached	71.5	82.0	70.8	78.5	71.3	78.4
Rise in temperature	22.7	32.0	23.3	29.5	22.8	27.9
Gain for dark surface	....	9.3	....	6.2	....	5.1
6 P.M.	66.5	71.5	70.0	74.5	71.0	77.0

* MOSIER, J. G., and A. F. GUSTAFSON, "Soil Physics and Management," p. 330, J. B. Lippincott Company, Philadelphia, 1917.

Specific Heat of the Soil.—In the determination of specific heat, water is taken as unity. The specific heat of dry soil is stated as a ratio of the amount of heat required to raise its temperature 1°C. as compared with that required to raise the temperature of

an identical weight of water from 15 to 16°C. According to Bouyoucos,[1] the extreme variations for mineral soils were from 0.193 for sand to 0.215 for loam, and for organic soil material the specific heat was 0.253. Notwithstanding these variations, 0.2 may be used as a satisfactory weight specific-heat figure for dry mineral soils.

As the water content of soils is increased, their weight specific heat rises. Consequently, more and more heat units are used up in raising the temperature of increasingly moist soils. More heat is required to raise the temperature of peats and mucks than that of mineral soils because of the high specific heat of organic matter and, also, because of the high water capacity of organic soils in the field.

Conductivity of Heat by Soils.—Loose, fine-grained, dry soils conduct heat slowly because of the air in the small pores. Air is a good insulator against the conduction of heat. Because water is a relatively good conductor of heat, moist soils permit conduction through them much more rapidly than do dry ones. In the spring, therefore, wet soils waste heat by conducting it down below the zone of the germinating seeds and plant roots at a time when concentration of heat in the seed and root zone would be highly desirable.

A definite lag in the downward movement of heat in soils has been noted. Smith[2] has shown that the maximum and minimum temperatures in a well-drained soil were attained from 5 to 7½ hours later at 1 foot than at ½ inch below the surface.

Soil temperatures for depths of 1 to 36 inches in sod at Urbana, Ill., are given as an average for the 10 years from 1905 to 1914 in Table 10.

Further evidence of this lag may be noted in Table 10. Also, it may be seen that in Illinois the temperatures at 36 inches below the surface fluctuated much less than at the surface. In California, Smith[3] found the maximum range in a well-drained alluvial soil at 4 feet to be 27°, and 9°F. at 12 feet below the surface.

Black mulch paper may be expected to raise the temperature of

[1] *Ibid.*, p. 12.

[2] SMITH, ALFRED, Effect of Mulches on Temperature, *Hilgardia*, Vol. 2, pp. 385-397, 1927.

[3] SMITH, ALFRED, Seasonal Subsoil Temperature Variations, *Jour. Agr. Research*, Vol. 44, pp. 421-428, 1932.

TABLE 10.—MONTHLY AVERAGE SOIL TEMPERATURES UNDER BLUEGRASS (*Poa pratensis*), URBANA, ILL., 1905–1914*
(Degrees Fahrenheit)

Depth, inches	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	31.3	30.9	40.0	50.9	62.8	72.7	76.7	76.4	68.6	55.1	42.4	35.6
3	31.5	30.6	39.6	50.7	62.2	72.0	75.8	75.8	68.2	54.8	42.8	34.9
6	32.5	31.5	38.9	49.6	60.4	69.8	74.2	74.0	68.2	54.9	43.4	35.3
9	33.2	32.1	38.3	49.2	59.8	68.5	73.5	73.3	67.9	55.8	44.3	36.2
12	34.4	32.7	38.0	48.7	58.8	68.2	72.8	72.9	67.6	56.9	45.4	37.8
24	39.4	37.2	38.0	47.2	55.3	62.7	68.3	69.5	66.7	59.5	49.9	43.5
36	41.4	38.8	40.2	46.1	53.1	60.5	65.7	67.5	65.9	60.4	52.1	45.8

* Unpublished data, Illinois Agricultural Experiment Station.

the surface soil to some extent. The use of such paper for this purpose, however, is not considered by Smith[1] to be an economical practice in the United States.

Water Content of the Soil.—Because of the high specific heat of water in comparison with that of soils, the mere presence of water in the soil raises its weight specific heat and, therefore, increases markedly the quantity of heat that is required to raise its temperature.

The evaporation of water uses much heat. If most of this heat comes from the moist surface soil, its temperature as a result is materially lowered. The evaporation of ½ pound of water requires 132.6 kilogram-calories at a temperature of 68°F. If all of the heat required came from the surface 6 inches of soil, the evaporation of 1/10 inch of water (0.52 pounds over 1 square foot) would reduce the temperature of soil with a normal moisture content by 28°F. Some heat may be supplied by the atmosphere and some by conduction from the soil below. A lowering of the temperature of the surface soil by 15 to 20°F. or more may be expected. On the basis of the data in Table 6, it is evident that any such lowering of the soil temperature in early spring may delay germination so long that the seed may decay under unfavorable conditions. Furthermore, such a lowering of the temperature of the soil retards the growth of crops both in early spring and in late autumn.

[1] SMITH, ALFRED, Effect of Paper Mulches on Soil Temperature, Soil Moisture, and Yields of Certain Crops, *Hilgardia*, Vol. 6, pp. 159–201, 1931.

From a practical standpoint, the removal of excess water from the soil by drainage is the most important single means of favorably affecting soil temperatures. Drainage lowers the specific heat of a moist soil and by reducing evaporation aids greatly in raising the temperature of the soil during the cooler periods of the year.

Questions

1. Name the factors that influence the color of soils, and discuss their relative importance.

2. What is the significance of color of subsoils in the cool, humid part of the United States?

3. In what way does the physical composition of soils affect their ability to support crops?

4. Distinguish between the physical properties of sands, silt, and clay, including colloidal clay.

5. Distinguish between texture and structure of soils, and indicate what may be done to maintain desirable structure.

6. What is the significance of volume weight of soils? State the relationship of specific gravity and porosity to volume weight.

7. Whence comes soil heat, and how is it lost?

8. What temperatures are required for germination and what for growth of different groups of plants?

9. Name the important conditions that influence soil temperatures.

10. To what extent and how may the farmer influence soil temperatures in a practical manner?

CHAPTER III

SOIL ORGANISMS

The living organisms of the soil are intimately associated with its moisture and its organic matter. In the absence of either, the organisms cannot function and soon become inactive. Higher plants, animals, and man are in turn dependent on the work of these lowly forms of plant and animal life. If by any change of conditions in nature these organisms were prevented from doing their full duty for a considerable length of time, higher life might cease on the earth. Fortunately, given moisture and organic matter, these organisms do their work without fail; and all forms of higher life, including man, are the beneficiaries. It should not be overlooked, however, that some organisms in the soil carry on harmful activities.

Soil organisms and soil organic matter are so interrelated that they might be treated simultaneously. It has, however, been arranged to treat the latter topic in the following chapter. Only a brief outline of soil organisms can be given here, the emphasis being placed on *what* they do and what the farmer may do to make conditions favorable for them.

MACROORGANISMS

The macroorganisms are those which may normally be distinguished with the unaided eye. Some of these are large, and others barely come within the range of ordinary human vision. Both animals and plants are found in this group.

Animals.—Among the animals of some importance may be mentioned rodents, millepedes, centipedes, worms, slugs, snails, and insects.

Rodents.—In this group are the prairie dog, woodchuck or ground hog, ground squirrel, chipmunk, mouse, and others. The work of this group was touched upon in Chap. I. Its significance lies partly in the grinding and mixing done by these animals in making their burrows. In addition, they carry organic matter

into their burrows as a supply of food and for nesting purposes. This eventually becomes a part of the organic matter of the soil. Although the work of the rodents is of real consequence, that of the worms and insects is of even greater importance.

Worms.—In temperate climates, the earthworm may be regarded as the most important member of this group from the standpoint of the quantity of work done. It is favored by a heavy, moist soil that is well supplied with organic matter and calcium. It does not thrive in coarse soils or in those heavier ones that are poorly supplied with organic matter or are poorly drained. This was learned early by many farm boys who sought their bait for fishing where a supply of organic matter had decomposed in a silt loam or heavier soil. The earthworm likes a soil that is reasonably well drained; it must not be waterlogged for any length of time. Nor must it become too dry, for then the worm goes down into the somewhat moister subsoil where it remains in a condition of reduced activity until rains again supply the topsoil with the necessary moisture. Then it comes back into the surface soil to resume its normal activities.

In moving about, it leaves open burrows in the soil. These may be noted in digging a heavy soil in spring or autumn or at other times if a mulch or rainfall has maintained a suitable moisture content of the soil. These open burrows serve as ideal channels for the downward passage of rainwater and thus markedly facilitate drainage. Aeration, too, easily takes place through these openings in the soil.

Organic matter is the principal food of the earthworm. It may be fresh or decomposed organic material. When it is decomposed, much soil and its organic matter are taken into the digestive tract by the earthworm. There, in the process of obtaining nutriment from it, the organic matter is further broken down chemically and mechanically. At the same time, not only are the soil particles reduced somewhat by rubbing mechanically against each other, but the digestive juices and the products of digestion act upon the soil and thus probably render the mineral plant nutrients more readily available to crops.

In this whole process, an enormous total quantity of soil material passes through the digestive system of all the earthworms in the topsoil of an acre of productive land. This modified soil material is ejected as the familiar "worm casts" that may often

be seen on the surface of moist, heavy soils, particularly in the morning after rains on soils that are relatively well supplied with organic matter and lime. Russell[1] quotes Darwin to the effect that earthworms bring to the surface the equivalent of ⅕ inch of soil a year. This would mean that once in 35 years the earthworm brings to the surface 7 inches of soil from below and deposits it on the surface. This soil material covers organic residues on the surface and thus aids other organisms in completing the breakdown of such material.

Moreover, the earthworm drags leaves and small pieces of residues into its burrows. Much organic matter is carried into the subsurface soil in this way. And this action may explain the relatively deep penetration of organic matter in heavy, moist soils as compared with that in sandy, acid soils in which few earthworms are found.

Earthworms are far more numerous in productive, medium-heavy soils that are well supplied with calcium and organic matter than in poor, acid soils, particularly if these are low in organic constituents. They are likewise far more numerous in well-manured soils than in those which receive little manure. The growing of legumes, as compared with grass alone, favors a denser population of earthworms.

Slugs and the larvae (worm stage) of certain insects perform in a limited way some of the same functions as earthworms, although they do not bring about the same turnover of the soil. They do, however, act upon organic matter and make burrows that facilitate percolation and aeration of the soil.

Nematodes[2] occur in large numbers in soils that contain goodly supplies of organic materials. According to Russell,[3] nematodes are about 0.5 to 1.5 millimeters in length. He classifies them roughly in three groups: "(1) Those living on decaying organic matter and possibly on bacteria, protozoa, and fungi. (2) Those parasitic on plants. (3) Those predatory on other nematodes, rotifers,[4] and small earthworms." Whether or not nematodes

[1] RUSSELL, SIR E. JOHN, "Soil Conditions and Plant Growth," p. 254, Longmans, Green & Company, New York, 1937.

[2] Nematodes are small worms.

[3] *Op. cit.*, p. 448.

[4] Rotifers are minute animals. Means of movement is provided by anterior cilia which in motion look like rapidly moving wheels.

have any direct influence on the productivity of soils is still uncertain. The parasitic nematodes are distinctly harmful to many field and greenhouse crops, including tobacco in the Southeast, tomatoes, potatoes, cucumbers, oats, sugar beets, red clover, and alfalfa. Some of the predatory nematodes may be helpful in controlling the numbers of the parasitic nematodes.

Insects.—Ants accomplish the turnover of the soil in the building up of "anthills," in somewhat the same manner as do earthworms. Ants also mix the subsurface with the surface-soil material, and they mix organic matter with all of it. The excellent growth of grass on and around anthills and around burrows of rodents has been noted frequently.

Plants.—Ordinary plants, especially their roots, play their part as well as do the larger animals. They aid in the distribution of organic matter, particularly in the penetration of the subsurface and the upper-subsoil strata. The larger fungi, such as mushrooms and lichens, make their contribution, as well. In addition, plant roots upon decaying leave open channels in the soil. This is particularly true of trees and of deep-rooted crops such as sweet clover, alfalfa, and many others. Although more or less occupied by the decayed organic matter, these openings materially facilitate both drainage and aeration in much the same way as do the burrows of earthworms.

MICROORGANISMS

The soil is literally alive with microorganisms. The animal forms are believed, at least at times, to run into billions in the top 7 inches of soil over an acre. The plant forms run into extremely large numbers, having been estimated to be as high in some cases as 1,000,000,000 billions to more than twice that number in 2 million pounds of topsoil. To be present in such stupendous numbers, animal and plant organisms in the soil are necessarily of infinitely minute size.

Animals.—Among the important animal forms are protozoa and nematodes. The latter, since they are of macroscopic as well as microscopic size, have already been discussed under the macroscopic classification of page 52.

Protozoa.—Protozoa are extremely simple, one-celled animals. Some of them, however, contain chlorophyll which places them on the border line between plants and animals. Soil organic

matter, which they absorb by diffusion through their body surfaces, is believed to be the principal source of nourishment for protozoa. Several forms, however, prey upon various groups of soil bacteria. It does not appear, however, that any probable reduction in the number of soil bacteria is likely to interfere seriously with the production of nutrients for economic plants. Protozoa are most numerous in soils that are well supplied with organic matter.

Plants.—In this classification are such forms as algae, fungi, actinomyces, and bacteria. In many respects, these are by far the most important of all the soil organisms.

Algae.—Algae have been found distributed so widely in soils that they may be regarded as being present almost universally. Several groups of algae living on or near the surface of the soil contain chlorophyll and actually produce organic matter which becomes part of the soil supply. They obtain nitrates and other nutrients from the soil. A second group lives deeper in the soil in the dark where chlorophyll cannot function. When favorable conditions with respect to light are established, however, their chlorophyll resumes its normal functions. These organisms live as saprophytes in that they obtain their energy from organic matter already in the soil. Under certain conditions, some forms or groups assimilate nitrates, others ammonia, and still others break down protein.

Algae are divided into three groups: the blue-green, which are often found in the warmer situations; the green, found in the cooler ones; and the diatoms, which are found in old gardens and in many other favorable situations. Certain algae thrive in acid soils, and others function best in neutral ones.

Algae may be credited with adding organic matter to soils, as, for example, on newly formed soil materials. In a symbiotic relationship with azotobacter and some other organisms, algae use elemental nitrogen from the soil air or fix atmospheric nitrogen. And some workers have found that certain algae fix atmospheric nitrogen independently. In swamp soils, algae use carbon from carbon dioxide and the oxygen thus liberated remains in solution and benefits such plants as rice.

Fungi.—Fungi like algae are widely distributed in soils, but fungi do not possess chlorophyll and, therefore, must obtain their energy from the soil organic matter. The molds and the mush-

room fungi are found in soils. According to Russell,[1] fungi in the soil under normal conditions may amount to as much as 7,500 pounds of living organisms (1,500 pounds of dry matter) in the plow soil of an acre. Fungi, in general, are aerobic; that is, they must have oxygen and are as a consequence more numerous near the surface of soils than in the deeper layers, more numerous in cultivated than in grassland soils, and more numerous in open, sandy soils than in poorly aerated clayey types.

Fungi live in acid, neutral, or alkaline soils, but liming acid soils depresses their numbers. Fungi and some of the other organisms work under soil conditions that are rather highly acid. Thus they widen the range over which higher plants are capable of life on the soil.

Fungi decompose soil organic matter in such a way as to be most economical of carbon. They can use nitrogen from nitrates, ammonia, amino acids, or protein. When they are forced to obtain energy from protein, they produce ammonia which is used by other organisms.

Actinomyces.—In form, actinomyces occupy a sort of transition stage between filamentous fungi and one-celled bacteria. The actinomyces are most numerous in well-aerated soils, especially those that have a reaction near or above a pH of 7 (see page 228). Numbers are greatly increased by applications of farm manure. Unlike fungi, actinomyces are sensitive to acidity. They decompose soil organic matter, even old humus (see page 68) and liberate the nutrients contained for the use of higher plants. The actinomyces utilize carbohydrates and also protein for energy. The odor of freshly plowed soils is credited to this group of soil organisms.

Bacteria.—Bacteria were the first soil organisms to be isolated and studied. They are unicellular plants, some of which live and function only in the presence of elemental oxygen and are, therefore, termed *aerobic*. Others which live in the absence of free oxygen but which obtain it from compounds of oxygen are termed *anaerobic*.

From the standpoint of the source of energy used, they may be divided into *autotrophic* and *heterotrophic* groups. The autotrophic bacteria live in whole or in part without organic matter. They obtain energy by the oxidation of such inorganic materials

[1] RUSSELL, *op. cit.*, p. 456.

as nitrite, ammonia, sulphur, hydrogen, and iron compounds and use carbon from carbon dioxide. The heterotrophic bacteria, in contrast, must have organic matter as a source of energy in order to function. In most soils, the heterotrophic bacteria are by far the predominant ones.

Bacteria occur in enormous numbers under relatively favorable soil conditions, there being possibly as high as 4 or 5 billions in 1 gram of well-manured soil.[1] Numbers are highest at neutrality, pH 7, and drop slowly on the alkaline side. On the acid side, the numbers drop very rapidly between pH 6.0 and 5.0 (see page 228) although considerable numbers are maintained at higher acidity. The number of bacteria increases very suddenly and varies greatly immediately following the introduction into the soil of organic matter such as farm manure or green manure or other source of available energy. After a period of large numbers, the count drops again when the source of energy is used up. The average weight of live bacteria has been estimated at 400 to 500 pounds in the top 7 inches of soil over an acre. Under especially favorable conditions, Thornton at Rothamsted estimated the live weight of bacteria as 1,500 to 5,600 pounds in the plowed soil of an acre of the manured soil on Barnfield.

Bacteria are infinitesimal in size, the largest being 0.004 to 0.005 millimeter in diameter. Their size considering their constitution places them, along with other minute organisms, in the range of colloidal matter. Since they are of such small dimensions and are present in enormous numbers, their total surface must also be very great. On the assumption of 1 billion bacteria to the gram of soil, it is clear what a large amount of contact is possible between the actual organisms and the colloidal material of the soil. Moreover, this large area of contact suggests an explanation of the marked influence of the organisms upon the soil and of the soil upon the organisms and also has a particular bearing on the effect of the pH of the soil on bacterial behavior in it.

Nitrogen and phosphorus are essential for the growth and functioning of these organisms. They multiply most rapidly at temperatures between 70 and 100°F. Moisture is, of course, essential for bacterial action. Moisture content and tempera-

[1] *Ibid.*

tures (page 46) that approximate the optimum for crop plants are favorable for the optimum functioning of many soil organisms.

THE RESULTS OF THE ACTIVITIES OF SOIL ORGANISMS

An idea of the activities of the organisms of the soil has been gained from the foregoing pages. The organic matter with which the organisms are concerned has been added to the soil in various ways. Some of it consists of the dead bodies of organisms; some is added by the chlorophyll-bearing algae; some as residues from crop plants, including roots; and some by man as animal and green manures.

Members of the larger sized animal population carry plant debris of one kind or another into the soil during their normal life processes. Much of this organic material has been altered both chemically and mechanically by the animals. Here the smaller organisms take up the task.

Beneficial Activities.—The smaller organisms attack organic matter in the soil in order to obtain energy and nutrients for satisfying their own needs for multiplication. Multiplication or the maintenance of its own kind on the earth is the one aim and purpose of all life in nature. Soil organisms, being no exception, work solely for their own benefit and not for that of crop plants or of man.

Crop plants and man are aided indirectly as a consequence of the ability of the higher plants to utilize some of the products of the reduction of plant materials to simple substances by soil organisms.

Destruction of Crop Residues.—The organisms bring about the decay of the organic matter that they find in the soil for the purpose of obtaining energy and nutrients from it. One group of organisms performs one step in the long process of simplification or decay of organic matter. Another group takes the next step, and others in turn carry on from where their predecessors left off until the task of reduction is completed. In addition to reduction, the building up, or synthesis, of organic matter is brought about by soil organisms in their own growth.

Making Nutrients Available to Crop Plants.—Among the essential products of the work of the organisms are ammonium compounds, nitrates, carbon dioxide, and sulphates. Carbon dioxide supplies carbon for the autotrophic forms and produces carbonic

acid, H_2CO_3, that most essential acid in the liberation of plant nutrients from the mineral part of the soil. During their acid stage, nitrates and sulphates act in a somewhat similar capacity.

The changes in nitrogen may be outlined as follows:

$$\begin{array}{ccccccc} \text{Organic nitrogen} & \longrightarrow & \text{ammonium} & \rightarrow & \text{nitrites} & \rightarrow & \text{nitrates} \\ \text{(Proteins, amino acids, etc.)} & \rightarrow & \text{salts-}NH_4 & \longrightarrow & NO_2 & \longrightarrow & NO_3 \\ \text{Decay and ammonification} & & & & & & \text{Nitrification} \end{array}$$

The steps, then, in the process of the simplification of nitrogen are decay, ammonification, and the formation of nitrites and nitrates. Though plants use nitrogen in the form of nitrate and ammonium compounds and probably others as well, the ordinary field and vegetable crops that grow on well-drained and well-aerated soils take up much of their supply of nitrogen in the nitrate form.

The making available of these compounds of nitrogen, and indirectly of the other nutrients of the soil, to the higher plants must be considered as the essential beneficial activities of the smaller soil organisms. Many of the chemical reactions that take place in soils are the indirect result of the work of these organisms. This work is essential because our crop plants cannot use farm manure, green manures, or crop remains directly. These organic materials must first be changed to the forms that plants can use for growth. And plants cannot feed upon the sand, silt, or clay particles that constitute much of the mineral part of soils. This material must first be acted upon, in part at least, by the products of the work of soil organisms. It seems clear, therefore, that all higher plants, and consequently the higher animals and man as well, are dependent on these lowly forms of plant and animal life, collectively referred to as *soil organisms.*

Fixation of Nitrogen.—The fixation of atmospheric nitrogen by one means or another is necessary in order that the higher plants may live and grow. Our crop plants other than leguminous ones cannot obtain nitrogen except as it is in the soil in a condition available for their use. Among the organisms that live in the soil are several groups that have the ability under favorable conditions to use nitrogen from the soil air for their growth. These organisms have no connection with higher plants, their particular requirement being soil organic matter as a source of energy.

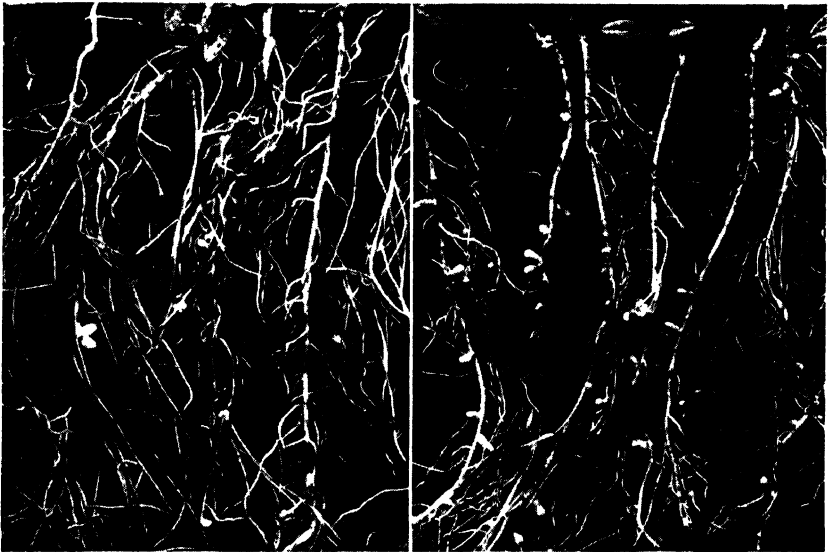
Equally or possibly more important is another large group of organisms that fix nitrogen. These are the symbiotic organisms that function in close association with the legumes and other nitrogen-gathering plants (Fig. 21). Among them are white, red, and mammoth clovers, sweet clover, black medic or yellow trefoil, alfalfa, beans, peas, bird's foot trefoil, crotalaria, lespedeza, dalea, cowpea, soybean, black locust, sesbania, and many others. Further details concerning the fixation of nitrogen by legumes are found in Chap. XII.

Seed not inoculated — Seed inoculated

FIG. 21.—Effect of inoculating seed on nodulation of peas. These plants were grown in soil that produced a crop of peas the seed of which was inoculated before planting the previous year. The roots on the left were grown from uninoculated seed; those on the right from seed that was inoculated before planting. Inoculation of legume seeds before planting often pays well. (*Courtesy of J. K. Wilson.*)

Much Human Labor for Organisms.—Man does a great deal of work that in a sense may be regarded as being mainly for the benefit of the organisms of the soil. Consider, for example, wheat. A crop of 40 bushels of grain weighs 2,400 pounds. The straw ordinarily weighs as much or more; and, according to Table 13, the roots recovered and the stubble weigh nearly 2 tons. In addition is an unknown quantity of tiny rootlets and root hairs that cannot be recovered and that, consequently, does not enter into this amount. The straw, roots, and stubble, therefore, con-

sidering that ordinarily man uses for his own food much less than the full weight of the grain, weigh four to six times that of the part actually consumed by man. Domestic animals, to be sure, use a part of the grain. The undigested portions, together with the straw, roots, and stubble, go back into the soil where they become food for the soil organisms. In a sense, therefore, it may be considered that in producing wheat the farmer works about 4 hours for the organisms and 1 hour for the benefit of himself and his family.

Harmful Activities.—Though much of the work of soil organisms is beneficial to the higher plants, some organisms under unfavorable conditions may undo the beneficial work of other organisms. Attention is called to these harmful activities because of their bearing on certain phases of the management of the soil. As already mentioned, water may stand in low places for some time after heavy rains. In order to obtain oxygen under these conditions, anaerobic organisms use the energy of organic matter in order to obtain oxygen from such compounds as nitrates, sulphates, and ferric oxides. If oxygen is split off from nitrate, NO_3, it is reduced to nitrite, NO_2, which green plants cannot use, the process being called "nitrate reduction." Nitrite may in turn be reduced and the nitrogen liberated and returned to the air as elemental gaseous nitrogen. The liberation of nitrogen in this manner is known as "denitrification." It is in this form that nitrogen occurs as about four-fifths of the atmosphere which higher plants can use only through the work of nitrogen-fixing organisms or by means of chemical fixation.

Similarly, sulphates and other oxygen-bearing compounds may be reduced with temporary detrimental effects. Fortunately, the practical remedy for these harmful conditions is drainage, tillage, and aeration, in short, the restoration of conditions favorable for the beneficial organisms.

Plant-disease Organisms.—In soils are found many organisms that under certain conditions of soils and crops produce plant diseases. A few representative organisms may be mentioned briefly here. The groups of actinomyces that cause scab on potatoes are widely distributed in soils. A relationship has been thought to exist between this group and the hydrogen-ion concentration (pH) of the soil. The groups of scab organisms operate over a range of pH which fortunately is narrower than

that over which the potato itself grows well. Of course, high acidity does reduce potato yields, but it controls scab. In contrast, scab is very plentiful near neutrality under some but apparently not under all soil and climatic conditions.

The fungus that causes "take-all" of wheat is more injurious on slightly alkaline than on acid soils. The organism that causes clubroot (finger-and-toe in Europe) of cabbage, turnips, and other cultivated cruciferae[1] functions best in acid soils, whereas the crops themselves are more thrifty on soils that are well supplied with lime. These points receive further consideration in Chap. X.

SOIL CONDITIONS BEST SUITED FOR THE ORGANISMS

Like crop plants, soil organisms require heat, moisture, nutrients, and oxygen. Crop plants require light with sunshine as their source of energy. Aside from the algae that have chlorophyll, soil organisms must have a source of energy in the soil. Except for the autotrophic group, this source of energy is organic matter. Fortunately, the conditions that favor the growth of crops are also, in general, suitable for the soil organisms. These conditions are discussed at some length in Chap. VII.

Questions

1. Distinguish between *macro-* and *microorganisms* in the soil.
2. Discuss the work of the macroorganisms in the soil
3. Discuss the beneficial activities of soil microorganisms.
4. What is meant by fixation of nitrogen by organisms?
5. Which organisms possess the ability to fix nitrogen in the soil?
6. Discuss the harmful activities of soil organisms
7. Under what conditions and to what extent do soil organisms cause diseases of crop plants?
8. In what way may man be regarded as working for the soil organisms?
9. What soil conditions are most favorable for the organisms, and what can the farmer do to promote these conditions?

[1] Cruciferae includes plants such as cabbage, turnips, and mustard.

CHAPTER IV

THE ORGANIC MATTER OF MINERAL SOILS

Organic matter is an essential constituent of all normally productive soils under field conditions. It is necessary for most of the soil organisms and is the natural source of nitrogen in the soil for higher plants. As here used *soil organic matter* includes all the nonliving material in the soil of either plant or animal origin.

The Sources of Native Organic Matter.—On the basis of observations upon what happens in such newly formed soils as recent volcanic ash, it appears probable that the chlorophyll-bearing algae were among the first agencies to add organic matter to soil materials. A possible source of the necessary nitrogen was the small amount of fixed nitrogen that was brought to the soil from the atmosphere by rains. Once organic matter had been added to the soil, the organisms that fix atmospheric nitrogen came into play. After this, the higher plants got a foothold, and as the plants grew they fell back on the soil, except as the aboveground growth may have been eaten by wild animals, who probably made their appearance not long after the plants became well established. The roots of plants were well distributed throughout the surface soil and extended into the subsurface and subsoil as well. The extent of penetration below the surface varied with soil conditions and the rooting habits of plants, since some of them rooted much more deeply than others. As plants died, their roots remained in the soil except as the earthworm or other animals consumed them.

During the recent past the leaves, twigs, and seeds and occasionally the branches and the trunks of trees fell on the surface of the soil where they decayed slowly. Some of this organic matter in soluble form passed down into the soil. And some of the coarse material accumulated and constituted the litter that covered the forest floor in natural wooded areas. In prairie regions, the grass roots penetrated and permeated the surface

soil. The stems, blades, and seed tops each autumn fell back on the soil and covered it much as the litter covered the forest floor. In either case, the aboveground material accumulated and decayed slowly, except as consumed by animals or carried into the soil where it became a part of the soil organic matter. Since the soil was moist in the root zone during much of the year and since the supply of oxygen was restricted, the decay of the root material was not very rapid. Thus over a long period of years did the native, or original, supply of organic matter come into existence and accumulate in the soil of the cooler climates.

In the warm to hot climates, even though conditions for the production of organic matter were exceptionally favorable, so also were conditions for its decomposition. Ants and other animals devoured a part of it, and much of the remainder was so completely oxidized that less organic matter accumulated in the soils of the warmer than in those of the cooler climates. This condition is well illustrated by the relative percentages of organic matter in the northern and southern sections of Illinois in the same type of soil. Eight samples of forested soils with a texture of coarse silt loam (deep loess) from the extreme southern part of the state contained 1.11 per cent of organic matter.[1] Four samples of the same soil type from the extreme northern part of the state had 3.86 per cent. Of a forested silt loam from the southern part, 18 samples had 1.5 in the surface and 0.58 per cent in the subsoil; in contrast, the same soil type from the northern part of Illinois had 2.4 and 0.96 per cent of organic matter, respectively. The extreme north and south ends of that state are separated by more than 400 miles. Latitude appears to effect similar differences in the prairie soils of that area. The brown prairie soil of the central part of the state carried 4.5 per cent in the surface soil, and that at the extreme north had 6.1 per cent of organic matter in the same kind of soil under similar conditions. It cannot, of course, be expected that such marked differences in organic content will accompany increasing differences in latitude.

Algae produce some organic matter now as they did when soils were in the process of formation, and crop roots that remain in the soil add to its organic content. Unused and unharvested

[1] MOSIER, J. G., and A. F. GUSTAFSON, "Soil Physics and Management," p. 145, J. B. Lippincott Company, Philadelphia, 1917.

aboveground parts remain on the soil, and the farmer adds plant and animal materials to replenish the wasting store of native soil organic matter.

Composition of Fresh Organic Matter.—Fresh organic matter, particularly in the green condition, such as succulent green-manuring crops, contain a high percentage of water. Average green plant material probably contains about 75 per cent of water, the remaining 25 per cent being dry matter. This dry matter, on the average, consists of about 11 per cent of carbon, 10 per cent of oxygen, 2 per cent of hydrogen, and about 2 per cent of mineral materials, usually referred to as *ash*. Of course, small quantities of nitrogen, sulphur, and other elements also are present. The mineral materials remain as ash when wood, straw, and other organic materials are burned.

Highly carbonaceous materials such as wood, straw, and roots contain very low percentages of nitrogen. Leguminous materials, in contrast, may contain as high as 5 per cent of nitrogen in young green clover. A nitrogen content of ½ to 2 or 3 per cent is commonly found in leguminous roughage, varying with maturity. From these figures, it is clear why the data quoted cover a range rather than being a specific percentage.

It should be stated in this connection that the composition of plant materials varies greatly even within a given species. According to Waksman,[1] cornstalks and rye straw have, respectively, 29.67 and 38.62 per cent of cellulose[2] as compared with 13.78 per cent in oak leaves. Oak leaves, however, have 30.3 per cent of lignin[3] in contrast with 10.78 per cent in alfalfa plants. The latter have 8.13 per cent of protein in comparison with 4.25 in oak leaves and 0.81 per cent in rye straw. Alfalfa contains much ash, 10.30 per cent; cornstalks have 7.53 per cent; and cypress wood only 0.76 per cent. Considerable variations in ash content, therefore, may be expected in the materials that enter into soil organic matter.

Organic Content of Mineral Soils.—The percentage of organic matter in soils varies over a wide range. Some coarse sandy

[1] WAKSMAN, S. A., "Humus," p. 95, The Williams & Wilkins Company, Baltimore, 1938.

[2] The fibers in flax, hemp, and cotton are typical examples of cellulose, $(C_6H_{12}O_6)n$.

[3] Lignin is a constituent of cell walls, high in carbon. Carbon content increases with maturity of plants. Lignin is resistant to decay.

and gravelly soils contain only a fraction of 1 per cent; peaty soils, in contrast, may have as high as 90 or 95 per cent of organic matter (see Chap. XIX). In productive mineral soils, the range is about 2 to 5 and occasionally 6 per cent of organic matter by weight. Around 4 per cent may be regarded as a desirable proportion of organic matter in soils of moderately high potential productivity. The activity of organic matter as well as the percentage present, however, deserves consideration.

Products of the Decomposition of Organic Matter.—From many points of view, plant tissues are highly complex in their make-up. Equally intricate is the breakdown, or simplification, of plant tissues by soil organisms. Only a brief outline of the subject can be given here.[1]

The decay of fresh organic materials in the soil may be indicated as occurring in four more or less distinct but orderly steps: (1) The starches, sugars, and water-soluble proteins are the first to be attacked and broken down by the organisms in the soil. (2) Next follow crude protein, pentosans,[2] and hemicellulose.[3] (3) Cellulose appears to be more resistant but still yields readily to the action of the organisms. (4) Decomposition of the oils, fats, waxes, resins, and lignin is very slow. These latter materials, especially lignin, contribute largely to the production of humus (page 68).

Of the carbonaceous part of organic matter, carbon dioxide, CO_2, and water, H_2O, are the end products. The nitrogen-carrying part, the proteins, are changed to amino acids, to ammonia, and finally to nitrites and nitrates.

Immediately after fresh organic matter, such as farm or green manures, is mixed with the moist warm soil, active decay becomes intense and results in the liberation of large quantities of carbon as carbon dioxide. This takes place simultaneously with a sudden and enormous increase in the numbers of the various soil organisms that are bringing about these changes. When the supply of fresh organic matter has been reduced, the numbers

[1] More detailed information is available in "The Nature and Properties of Soils" by T. L. Lyon and H. O. Buckman, "Soil Conditions and Plant Growth" by Sir E. John Russell, "Humus" by S. A. Waksman, and in other books and in various technical bulletins.

[2] Pentosan, a complex carbohydrate, found widely distributed in plants, fruits, gums, wood, hay.

[3] Hemicellulose, a form of cellulose that decomposes easily in dilute acids.

of organisms and the evolution of carbon dioxide taper off simultaneously because the organisms have used up the more readily decomposable carbonaceous part of the plant tissues. Some of the more resistant materials, such as oils, fats, resins, and lignins, remain in the soil much longer.

Humus.—Highly resistant organic material in the soil that is dark brown to black in color is often called *humus.* In its development by soil organisms, lignin is believed to have been relatively prominent. Humus is variable in nitrogen content.[1]

Though subject to further breakdown by organisms, humus is relatively stable in soils. The supply is replenished through the decay of fresh plant tissues as they are added to the soil. Thus the soil is assured of a supply of humus.

To humus is credited many of those favorable conditions in the soil which are usually ascribed to soil organic matter. Though humus may not be a constant, definite, and distinct chemical substance, such as carbon dioxide, it does appear to possess fairly definite, chemically reactive properties. Humus is colloidal in nature and, therefore, has very high internal surface. In fact, it is regarded as being six or seven times as effective with respect to such surface phenomena as the absorption of gases or vapors as are inorganic colloidal materials. In addition, humus possesses both acid and base-exchange properties.

The dark-brown to black color of some soils is credited to humus which enables soils to hold increased quantities of certain nutrients. Other important effects of humus in soils, are with respect to granulation and absorptive capacity.

The Use of Simple Products by Crops.—It has already been indicated that crops can use only the simpler products of the decomposition of organic matter and also that soil organisms are the agency of accomplishing this simplification. In the decay of organic matter, carbon appears as carbon dioxide and bicarbonates. Although liberated in the soil, carbon dioxide reaches the atmosphere by diffusion and may be taken up and

[1] Hilgard, "Soils," pp. 136 and 137, The Macmillan Company, New York, 1914, gives 5.29 as the percentage of nitrogen in humus from the humid California soils, 8.38 per cent for subirrigated soils, and 15.23 per cent in the humus from the arid regions in California. Hawaiian soils averaged 3.78 per cent of nitrogen but varied from 1.71 to 6.07 per cent. His average was 4.23 per cent of nitrogen in the humus of humid soils in general.

used again by green plants. Moreover, as carbonic acid, it acts upon the soil minerals and aids in rendering the nutrients in them available to crops. As ammonia to some extent and as nitrates in general, crops take up their nitrogen in the form of these simple products of the decay of organic matter.

Other products include simple carriers of such elements as phosphorus, sulphur, and potassium that had served the plants from which they came as nutrients. Thus are plant nutrients used over and over again in nature's economy of materials. From man's standpoint, this economy of nutrients, particularly phosphorus, is fortunate indeed because it occurs in soils only in small quantities.

Ratio of Carbon to Nitrogen.—Plant tissues vary widely in their content of carbon and nitrogen. This variation occurs not only in different parts of the same plant and at different stages of maturity but also as between classes of plants. The straw of grains, such as wheat and rye, is particularly high in carbon. In contrast, the leaves of alfalfa are high in protein and, therefore, nitrogen. In fact, the leaves contain about 22 per cent and the stems about 10 per cent of protein. The whole group of leguminous plants are high in nitrogen in comparison with nonleguminous ones. The relationship between the percentage of carbon and that of nitrogen in organic matter or soil is referred to as the *carbon-nitrogen ratio.*[1] It is the figure that represents the number of times the percentage or pounds of carbon are of those of nitrogen in organic materials.

In Table 11 are given the percentages of carbon and nitrogen and the carbon-nitrogen ratios for some representative plant materials.

Wheat and oats may be regarded as fairly representative of the cereal grains, their C:N ratios being 20 and 23, respectively. These ratios are relatively narrow, but it must be borne in mind that these figures cover the grain and not the straw. Rye straw is representative of the straw of cereals, but oat and barley straws may be expected to have a somewhat narrower C:N ratio. In Table 12, according to Russell, the C:N ratio for cereal stubble and residues is 90 or more. In comparison, it is

[1] The C:N ratio of organic materials may be found by dividing the percentage or pounds of carbon by the percentage or pounds of nitrogen in them.

TABLE 11.—PERCENTAGE OF CARBON, HYDROGEN, OXYGEN, NITROGEN, AND ASH CONTENT OF VARIOUS PLANT MATERIALS (DRY BASIS) AND THEIR C:N RATIO*

Plant material	Carbon	Hydrogen	Oxygen	Nitrogen	Ash	C:N† ratio
Wheat (grain)	46.1	5.8	43.4	2.3	2.4	20.04
Oats (grain)	50.7	6.4	36.7	2.2	4.0	23.04
Rye straw	49.9	5.6	40.6	0.3	3.6	166.3
Potatoes	44.0	5.8	44.7	1.5	4.0	29.33
Peas	46.5	6.2	40.0	4.2	3.1	11.08
Leaves of red beet	38.1	5.1	30.8	4.5	21.5	8.46

* GIBSON, R. J. H., "Jost's Plant Physiology," p. 3, Oxford, Clarendon Press, New York, 1907.

† Added by the author.

TABLE 12.—PERCENTAGES OF CARBON AND NITROGEN AND C:N RATIOS IN PLANT CONSTITUENTS AND IN SOIL ORGANIC MATTER*

Plant constituents	Approximate percentage composition		C:N ratios
	Carbon	Nitrogen	
Proteins	50	16	3
Whole plant:			
Dry organic matter, about	45–50	1.5–3.5	15–30
Residues and stubbles:			
Cereal, about	45	0.5 or less	90 or more
Leguminous, about	50	2.0 3.5	13–25
Rotted residues			
Farmyard manure (artificial)	56	2.6	20
Fungus mycelium	38–48	2.5–8.0	6–17
Soil organic matter			
As whole	58	5–6	10
Humic acid	56	5–6	10

* RUSSELL, SIR E. JOHN, "Soil Conditions and Plant Growth," p. 345, Longmans, Green & Company, New York, 1937.

interesting to observe that the residues and stubble of legumes have C:N ratios of 13 to 25, very much narrower and because of their higher nitrogen content correspondingly more desirable in the soil than those of the cereals. Artificial manure (page 304) has a C:N ratio of 20 and soil organic matter a C:N ratio of

approximately 10. Virgin prairie soils and those which have received regular additions of organic matter have C:N ratios somewhat higher, being up to 12 or slightly more occasionally. Cultivation reduces or narrows the C:N ratio of old soils.

MANNER OF LOSS OF ORGANIC MATTER FROM SOILS

Organic matter may be lost from soils in any or all of a number of ways. In fact, it is such an active material that in the presence of bacteria under favorable conditions it is broken down and in part dissipated by them, if it is not lost in other ways.

By Erosion.—Since dry organic matter is light in weight, fragments of it on the surface float readily and are carried from the land by runoff water. In addition, organic matter in the soil itself is lost by erosion.

By Fires.—In the early days of American agriculture, fire was, and in places today still is, resorted to for ridding the surface of the soil of the residues from previous crops. For a few years, the destruction of such organic matter did not reduce yields seriously. As the years have passed, continued burning of such residues as the stubble of small grains and stalks of corn and cotton, has reduced the organic content of soils to a point that is now limiting yields on many soils. Not only does burning destroy all the carbonaceous material that could be decomposed in the soil with many beneficial effects, but the nitrogen contained is released to the atmosphere—a dead loss to the soil and to crops. Obviously, unless crop residues are definitely known to be infested with harmful insects or crop diseases, burning them ordinarily produces only harmful effects on soils and crops (Fig. 22).

By Decay and Leaching.—The decay of organic matter in soils cannot and need not be prevented. Decay is perfectly natural, in fact necessary, if plants are to grow. Plants require nutrients that can be provided only through decay by the organisms of the soil. This decay and liberation of plant nutrients goes on regardless of whether or not crop plants are present to use them. If plant roots are not present to take up the nutrients, they are lost by leaching out in the drainage water. By reference to Table 16 (page 100), it is seen that cropping reduced percolation by one-third. In Table 18 (page 103) may be seen the very marked reduction in the loss of nutrients, nitrogen in particular,

in drainage from cropped soils. Cropping the land, therefore, is a way of avoiding heavy loss of nitrogen in drainage. If land in humid regions is not needed for crop production, cover crops that conserve nitrogen and other nutrients may well be grown. The cover crops may be plowed down and the nutrients conserved by them released for use by subsequent crops.

FIG. 22. Destruction of organic matter. Not only is the organic matter in the cornstalks destroyed but the nitrogen in them is lost by its release to the atmosphere. Burning straw, small-grain stubble, corn, cotton, and broom-corn stalks, and other coarse residues is a quick way of getting rid of them but soil organisms and crops are deprived of the organic matter and plant nutrients in them. (*Courtesy of Illinois Agr. Exp. Sta.*)

By Cropping.—Cropping facilitates the decay of organic matter in the soil, and crops use nutrients that become available from organic matter in the process of decay. As stated in the previous paragraph, nitrogen and other nutrients after being made available are lost from uncropped lands. Crops use these nutrients, and when the crops are harvested they are removed from the land. In the case of a crop such as wheat or potatoes, the nutrients obtained from the soil are, in the main, not returned to the soil from which they came. To that extent, therefore, cropping removes from the soil products of the decay of organic

materials. Loss of soil organic matter in harvested crops in general is desirable and should be encouraged. Ways of making good such losses will be discussed presently.

By Fallowing.—In the drier areas (see Dry Farming, Chap. VI), the soil is clean cultivated during alternate years in order to accumulate moisture for crops. During the year of fallow, the soil organisms destroy organic matter if ample moisture is present. Rains leach soluble materials, particularly nitrates, from the body of the soil itself. Fortunately, from the standpoint of loss of organic matter, rainfall in these areas is light. On the other hand, much of the growing-season rainfall comes in heavy showers that cause surface runoff losses in addition to those by leaching. Even though moisture, rather than supply of plant nutrients, determines crop yields, in these drier regions losses of organic matter may well be held to a minimum.

WAYS OF RETURNING ORGANIC MATTER TO THE SOIL

Though we have no way of holding organic matter unchanged in moist soils, there are numerous ways of adding plant materials to the soil. Since the organic content of the soil cannot be built up rapidly and maintained at high levels at reasonable cost, the alternative is making annual or at least frequent additions of plant materials to the soil.

Addition of Fertilizers and Lime (If Needed).—The use of fertilizers wherever soils are deficient in one or more of the important plant-nutrient elements may be expected to increase crop yields under normal conditions. At the same time, the plant is producing a large root system and a larger growth of the usual unharvested part of plants. Adding phosphorus is particularly important on much of the humid area of the United States because of the widespread deficiency of this element in the soil. Additions of potash in some form are beneficial on many sandy and gravelly soils in humid areas, for potash in available form is not present in sufficient quantities. In the more intensive agriculture, such as in vegetable and fruit production, the use of nitrogenous fertilizers in addition to increasing yields may aid in producing more residues as well as more cover-crop material to go back into the soil.

On soils that are too acid for good growth of legumes, the addition of some form of agricultural lime is essential (Chap. X).

Not only do the legumes, if inoculated, fix nitrogen for their own use, but also they supply nitrogen for nonleguminous crops as well. The residues from legumes readily yield nutrients to other crops.

Return of Crop Residues.—The term *crop residues* includes the stubble and roots of such crops as the small grains; hay crops; the grain and forage sorghums; soybeans; roots and stalks of corn, cotton, and broom corn; and the roots and tops or trimmings of vegetables. Under certain conditions where straw is not needed for bedding livestock, straw and cane pomace as well as other leftovers from crops are regarded as crop residues. The burning of any of these materials under normal conditions is poor soil economy and bad soil management (Fig. 22). Not only does the fire destroy the carbonaceous material that might serve as a source of energy for soil organisms and be of real service in maintaining favorable physical conditions, but it also liberates the nitrogen present to the atmosphere. Cornstalks are sometimes so coarse and heavy as to interfere with the preparation of the seedbed for the succeeding crop, and they remain on the surface to be raked up in the clover following oats. Even if they are a nuisance occasionally, it is seldom advisable to burn them except when they are infested with injurious insects or plant-disease organisms. It is better to cut them up sufficiently to render them less of a nuisance. Stubble of small grains and the aftergrowth of weeds may be sufficient in wet years to be troublesome. Even so, these residues usually ought to be plowed under and not burned.

The roots of crops are well distributed in a highly desirable way throughout the soil. The stubble is well spread over the surface so that when turned under it, too, is mixed uniformly with the soil. The stubble and roots of crops are often not fully appreciated. This is particularly true with respect to the quantity of them in and on the soil. Stocklasa in Central Europe determined the weights for grains and legumes. His data are given in Table 13.

Although the yields of these crops are not given, it is surprising to note that the dry material of the roots and stubble of the cereals amount to about 2 tons to the acre. It is even more surprising that the roots and stubble from red clover amount to 4, and from alfalfa to 5 tons to the acre. It is little wonder that

many crops make such excellent growth following these and other leguminous crops. From the foregoing, the value of residues to crops and their importance to the soil on a long-term basis are apparent.

TABLE 13.—WEIGHT OF STUBBLE AND ROOTS AN ACRE LEFT IN THE SOIL AFTER HARVESTING CROPS*

Crop	Dry plant material; pounds per acre	Carbon, per cent
Oats	3,823	49.1
Wheat	3,850	49.7
Rye	3,861	44.8
Barley	4,366	50.6
Red clover	8,174	46.9
Alfalfa	10,200	45.2

* STOCKLASA, J., quoted by W. W. Wier, "Soil Science," p. 337, J. B. Lippincott Company, Philadelphia, 1936.

Straw, stalks, potato tops, and similar materials that have been cut loose from the roots are most useful if they are well distributed before being plowed under.

Return of Green and Farm Manures.—Farm manures and green manures may be returned to the soil to excellent advantage. Farm manures, if protected from undue loss, produce goodly increases in crop yields. The management and utilization of farm manures and the production and management of green manures are discussed at length in Chaps. XIII and XIV.

Pasturing of Crops.—The grazing off of certain crops has some advantage from the standpoint of labor on the farm. The droppings from pastured crops are fairly well distributed over the grazed area. With ordinary barnyard manure, however, considerable loss occurs between the harvesting of the crop and its return to the soil. With pasture droppings, on the other hand, the loss is reduced to a minimum.

By reference to Table 40 (page 283) a general idea may be gained of the recovery from pasturing grasses, red clover, and alfalfa; the values are seen to be approximately 580, 680, and 660 pounds of dry matter, respectively, to the ton of dry matter in the feed eaten. The return of nitrogen was 30, 33, and 19 per cent, respectively. Though a recovery of 580 pounds of dry

matter from 1 ton of dry matter eaten as green pasture grasses may seem low, it is higher than the average quantity usually returned to the soil from the feeding of hay and grain. Though highly variable, these figures are suggestive of the recoveries that may be expected under these conditions.

The actual poundage of dry matter recovered as manure per ton of hay consumed is greater than that from grasses. The quantity from grain, particularly corn, is much lower. The other important point is that a heavy loss of both nitrogen and organic matter from manure takes place between its production and its actual return to the soil. This statement is based on the average method of handling manure on the farm (Chap. XIII).

Rotation of Crops.— Legumes are grown in rotations of crops. Nonlegumes, such as corn, cotton, wheat, and grasses, are often grown year after year on the same land. In a humid area, a rotation such as (1) corn, (2) oats, (3) clover, and (4) timothy may be considered. This is a typical one for parts of the dairy-farming section of the Northeast. Some legume growth will be made in the oats, during the clover year, and in the timothy but not in the corn unless an annual legume is planted with it. Thus, in 3 out of 4 years, leguminous material is produced on the land in this rotation. Furthermore, in a rotation such as this, corn is the only crop that is a heavy "user" of organic matter. Oats is intermediate, and the two hay crops may be expected to average some gain, particularly if the manure resulting from feeding the hay on the farm is conserved and returned to the soil reasonably soon after it is produced.

From these general statements, it should be evident that, as compared with corn or timothy grown continuously over a long period, a 4-year rotation such as corn, oats, clover, and timothy is superior. The rotation is superior from the standpoint both of crop yields and of the maintenance of the organic content of the soil.

EFFECTS OF ORGANIC MATTER ON THE PHYSICAL CONDITION AND PLANT-NUTRIENT SUPPLY OF SOILS

Organic matter is needed in all soils, but it may be more beneficial in some than in others. A brief discussion of the effects of organic matter on the physical condition of soils is presented in the following paragraphs.

Promotion of Granulation.—Organic matter and clay with some of both in colloidal form have been regarded as essential for the development of a suitable degree of granulation, or aggregation. This condition is sometimes described as one of *crumb* structure. Peats that have some organic matter in colloidal form granulate freely upon wetting and drying. It is conceivable that soils well supplied with colloidal clay may assume a granular condition, but the presence of organic matter in colloidal or soluble condition greatly facilitates the development of this highly desirable structure. Alternate wetting and drying which are accompanied by alternate swelling and shrinking of the

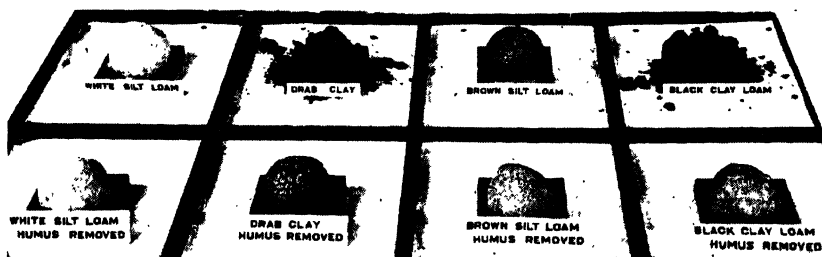



FIG. 23.—Effect of the removal of organic matter on the granulation of soils. The soils on the opposite side of the tray are normal while the soluble organic matter has been removed from those in the foreground. The two silt loams did not possess enough clay for granulation. Alternate wetting and drying of the drab clay and the clay loam with their normal organic content, however, brought about distinct granulation. In addition, calcium may have played a minor role. (*Photographed at the University of Illinois by the author.*)

organic matter are believed to have much to do with bringing about granulation. Freezing and thawing alternately also are credited with helping to bring about granulation (Fig. 23). In this connection, water is probably of at least equal effectiveness with the organic matter. Peele's[1] work suggests that soil organisms play an important role in granulation of soils.

Holding Sand Particles Together.—The more completely decayed organic matter, under certain conditions, is evenly distributed over the surface of the soil particles. Being colloidal, gelatinous, or sticky, it tends to hold the particles together, especially when moist. Moreover, the smaller pieces of the fresher organic materials occupy the large spaces between the

[1] PEELE, T. C., Microbial Activity in Relation to Soil Aggregation, *Jour. Amer. Soc. Agron.*, Vol. 32, pp. 204–212, 1940.

sand grains and, particularly when moist, tend to hold the particles together. And since organic matter holds water tenaciously, this tendency to bind the sand together persists.

Retention of Moisture.—Moderately fresh organic matter absorbs water and holds it as does a sponge. In fact, certain types of plant materials hold several times their own weight of water. Well-granulated heavy soils and coarse-grained ones possess large pores. These pores may be so large that water passes out of them freely. The addition of organic matter over a period of years, particularly if it is not decomposed rapidly, may partly clog or bridge the pores of sandy soils. Upon swelling, organic matter partly closes the pores that are too large and thus enables coarse, open soils and coarsely granulated heavy ones to hold more water than if they were very low in this constituent. In general, it is likely that this effect of organic matter is greater in coarse than in medium-textured soils. In the drier, warmer areas, the decomposition of organic matter is so rapid that this effect of organic matter does not extend over long periods.

Reduction of Losses by Erosion.—By increasing granulation and consequently percolation of water into the soil, organic matter may reduce the loss of water and, therefore, runoff and erosion. Granules of soil are much larger than individual clay or silt particles and, hence, more difficult to move than the smaller particles. The fresh, fibrous organic matter of roots and top material that is plowed under tends to hold the soil together mechanically and as a result checks erosion (Chaps. VIII and IX).

Rise in Temperature of the Soil.—Organic matter, particularly the old, well-decomposed portion, is dark brown or black in color. By its distribution over the surface of the particles, it tends to impart a dark color to the soil. Dark colors absorb heat on bright days and thus raise the temperature of the soil. As already stated (page 47), in fields where light- and dark-colored soils occur with essentially similar drainage and physical make-up, crops germinate and make more rapid growth on the dark than on the light-colored soil. These differences may be credited, in part at least, to the effect of the dark color.

Promotion of Biological and Chemical Action.—Organic matter supplies energy for the organisms of the soil. Most of them, in fact, are wholly dependent on supplies of fresh organic matter for energy. Many phases of this situation were discussed in

Chap. III. As a result of their life processes, the organisms produce many acids which attack the inorganic portion of the soil and aid materially in rendering nutrients available to plants.

Supply of Nitrogen for Crops.—Soil organic matter from different sources and in varying stages of decomposition contains varying proportions of nitrogen. Whatever the amount of nitrogen present, it is eventually made available to plants. If no organic matter were added to unfertilized soil for a long period, the nitrogen content would become lower and lower and crop yields would be similarly affected. Salter[1] states that in Ohio the better soils are losing organic matter at the rate of 1 ton to the acre annually. Good soil-management practices generally tend to use up the organic matter more rapidly than do poor practices. Even so, rapid decay of organic matter liberates nitrogen and other nutrients to crops and, therefore, should be encouraged. Simultaneously, good management of the rotation requires frequent returns of organic matter in order to maintain an ample, revolving supply of it in the soil.

Questions

1. What are the principal sources of organic matter in the soil?

2. Discuss the composition, decomposition, and the use by crops of the simple products of decomposition.

3. How is organic matter lost from soils?

4. Discuss the control of losses of soil organic matter.

5. Outline practicable ways and means for returning organic matter to the soil.

6. What are the effects of organic matter on the physical condition of soils?

7. In what ways may additions of organic matter aid in the control of soil erosion?

8. Discuss the relation of organic matter to the supply of nitrogen for crops.

[1] SALTER, R. M., "Timely Soil Topics," p. 4, Ohio State University, Columbus, May, 1921.

CHAPTER V

THE RELATION OF WATER TO SOILS AND PLANTS

Water has already received attention in its relation to the production of soil material by the weathering of rocks. Water played an important role in the solution and transfer of materials in the development of the soil profile and also in the formation of the soil itself. On the following pages, consideration is given to the varied relationships of water to soils and plants.

FORMS OF WATER IN THE SOIL

Three forms of water occur in soils which for present purposes may be regarded as being closely related to the forces by which water is held in the soil. The three conventionally recognized forms are *hygroscopic*, *capillary*, and *gravitational*, or *free*, water (Fig. 24).

Hygroscopic Water.—Soils that are allowed to become dry in the air at ordinary temperatures still hold varying percentages of water. As one observes an air-dry soil, no water is visible. That water may be readily driven out of an air-dry soil at the boiling temperature of water, however, establishes the fact of its presence in the soil. This water is held so tightly that exposure to temperatures somewhat above the boiling point of pure water for a period of 8 hours or more is required to expel it from the soil.

The force by which this water is held in the soil is regarded as equivalent to about 20,000 atmospheres, or nearly 300,000 pounds to the square inch (an atmosphere being 14.7 pounds to the square inch at sea level). Under such pressure, this water is probably not in what we ordinarily regard as the liquid form. It is held as an extremely thin film on the surface of the soil particles, in and on the organic matter, and on the inner as well as the outer surface of the soil aggregates or granules. This film, according to Mattson,[1] is not more than 4/1,000,000 or

[1] MATTSON, SANTE, Forms and Functions of Water, *Soil Science*, Vol. 33, pp. 301–322, 1932.

5/1,000,000 millimeter in thickness, or 15 or 20 layers of molecules of water. It is little wonder that water in so thin a film and so tightly held cannot move about in the soil. Its movement appears to be confined to evaporation and condensation.

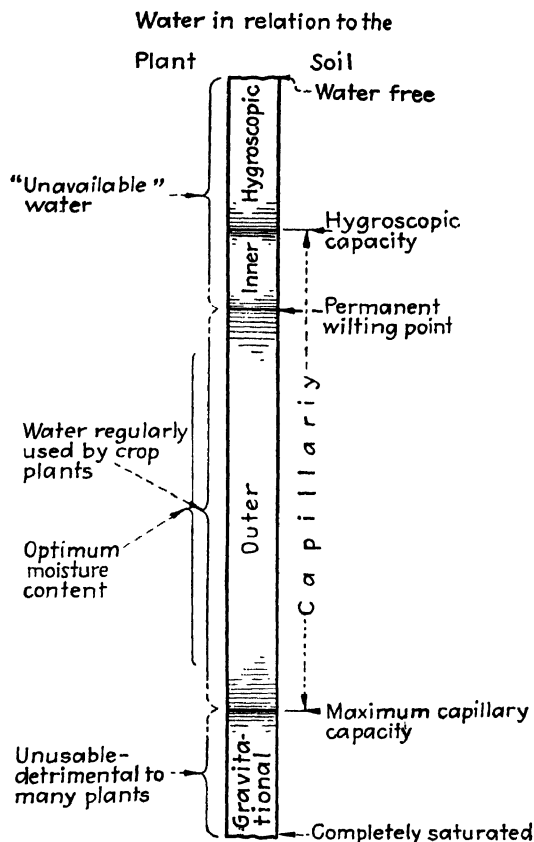



FIG. 24.—Relationship of water to plants and soils.

The percentage of hygroscopic water actually present in an air-dry soil may be readily determined.[1] The loss of weight in the oven obviously is the hygroscopic water that was driven off by heating. All percentages of water in soils are calculated on

[1] A small sample, usually 5 grams of air-dry soil, is accurately weighed in a glass weighing bottle fitted with a ground-in stopper. The sample, bottle, and stopper are placed in a constant-temperature oven at a temperature of 105 to 110°C. for a period of 8 hours or more. Upon removal from the oven at the end of this period, the stopper is replaced tightly in order to exclude moist air. The sample is cooled in a desiccator after which it is weighed

the basis of the weight of water-free soil. Otherwise, the water itself is included in the base of calculation, and this introduces an undesirable variation in the base. The water-free soil, therefore, is the only possible, relatively constant basis for calculation.

Soils vary greatly in the quantity of hygroscopic water they contain. Since the water is held as a thin film on the surface of the soil particles, the quantity of water held varies with the surface area exposed and with relative humidity. Coarse soils, such as sands and gravels, have less than 1 per cent of hygroscopic water, silt loams that contain some clay and a fair supply of organic matter may hold 5 to 8 per cent, and heavy clay soils well supplied with organic matter may contain up to 12 or 15 per cent and even more. Soils of high organic content or exceptionally high colloidal content carry as high as from 18 to 21 per cent of hygroscopic water. Colloidal clay and colloidal organic matter largely determine the quantity of hygroscopic water which can be held by soils.

Hygroscopic Coefficient.—The hygroscopic coefficient, or capacity, is the percentage of hygroscopic water a thin layer of soil is capable of taking up from a saturated atmosphere. To obtain this, the usual method is to expose a thin layer of soil in a desiccator containing water or a weak solution of sulphuric acid (3.3 per cent). A relatively constant temperature is essential in order that the soil and vapor may come to equilibrium. In a rising temperature, equilibrium would not be attained. If, on the other hand, equilibrium has been reached and a drop in temperature occurs, water may be condensed in the soil. Both rising and falling temperatures must be avoided.

The hygroscopic coefficient may be calculated from other soil-moisture constants, and these constants, likewise, may be calculated from the hygroscopic coefficient. Moreover, the hygroscopic coefficient, because of its relationship to the total internal surface exposed by a soil, is a general measure of the combined organic-matter and colloidal-clay content of the soil.

---

accurately on an analytical balance. The percentage of hygroscopic water may then be calculated as follows:

$$\frac{\text{Weight of air-dry soil} - \text{weight of water-free soil}}{\text{Weight of water-free soil}} \times 100$$

$$= \text{per cent of hygroscopic water}$$

Capillary Water.—When a light rain falls on air-dry soil, it takes up and holds the water against the pull of gravity. Water so held is called *capillary* water. In the soil, no sharp line exists between the different forms of water. In fact, a transition zone marks these division points. The capillary water that occurs in an extremely thin film about the soil particles is called the *inner* capillary water. This film, however, is thick in comparison with the exceedingly thin film of the hygroscopic water.

As soils have more and more water, the capillary films become thicker and thicker until finally the sharper angles between the particles are occupied by water. With a further increase, still more water occupies the angles, and even the interstices themselves may be nearly filled with water. This is known as the *outer* capillary water.

Factors Affecting the Amount of Capillary Water in Soils.—A number of conditions affect the quantity of capillary water that can be held by soils. Enumeration of these conditions with a brief explanation of each is attempted in the following paragraphs.

The Organic Content of the Soil.—Soils that are well supplied with organic matter hold considerably more capillary water than do those that contain little organic matter. Organic matter itself takes up water like a sponge, even to the extent of several times its own weight. Thus, organic matter increases directly the water-holding capacity of soils. In coarse soils, such as sands and sandy loams, organic matter may occupy the larger interstices. Thus, it may bridge vacant pore spaces that are otherwise too large to hold water. By enabling water to occupy spaces that are otherwise empty, organic matter increases the ability of coarse soils to hold capillary water.

In fine-grained soils, organic matter brings about improved granulation or aggregation of the particles and thus increases the proportion of pore space. Many of these individual pore spaces are of the size that holds capillary water to excellent advantage. Increased capillary capacity, or water-holding power, of heavy soils may enhance their value, particularly during periods of drought.

The Temperature of the Soil.—The temperature of the soil obviously controls the temperature of the water held by it. "Slow as molasses in January" is a familiar saying. This pro-

verbial slowness is associated with the high viscosity of molasses at the temperature that ordinarily prevails in a cold climate during winter. Likewise, the viscosity and surface tension of water are high at low temperatures. This condition helps to explain the very high water content of even coarse soils late in the fall when the temperature is near the freezing point.

The Texture and Structure of the Soil.—The coarser textured soils do not hold capillary water well, because the individual pores are so large that surface tension is unable to hold water, except in the sharper angles. Compacting coarse soils may increase their water-holding capacity. In medium-grained soils, on the contrary, surface tension may hold the pores full of water or nearly so. Therefore, if the total porosity is identical, the medium-grained soil holds more capillary water than the coarse-grained one. In addition, however, the coarse usually has less pore space than does a medium-grained soil.

As already indicated, a fine-grained soil in the single-grain condition may be so compact as to hold a relatively small quantity of water. If granulation is brought about, the size of the pore spaces between the granules is increased greatly as compared with the space between tiny individual particles. Moreover, the granules themselves contain a high degree of porosity. When, as is often the case, all this pore space is filled to the extent that surface tension can hold it, the soil contains a large percentage of water.

Gravitational, or Free, Water.—During a moderately heavy shower, water percolates into the soil. After a time, the pores become completely filled, or the soil is said to be "saturated" with water. This water is free to move in response to the pull of gravity; in fact, gravity is the force that has carried the water into the soil. Owing to its method of movement, this is called *gravitational,* or *free,* water.

MOVEMENT OF WATER IN THE SOIL

The different forms of water in soils are subject to movement by different forces. In fact, the name of the various forms is associated with the type of movement or the force with which the water is held in the soil.

Movement of Hygroscopic Water.—As already stated, hygroscopic water is very tightly held in an exceedingly thin film on

the surface of the soil particles, as well as on both the internal and the external surface of the aggregates. In fact, so tightly is it held that hygroscopic water is regarded as being in the solid rather than in the liquid form. How then can it undergo any movement? It does not move in the same sense as do the other forms of soil water.

The amount of hygroscopic water in soils varies with the relative humidity of the air to which air-dry soil is exposed. Since the quantity of water in air-dry soils varies—and this may be easily demonstrated—it must undergo movement. And the fact is that when air-dry soil is exposed to air of decreasing humidity the soil slowly loses moisture by evaporation in order to be in equilibrium with the humidity of the enveloping air. Conversely, if exposed to an atmosphere of increasing humidity, air-dry soil takes up moisture. Vapor condenses from the air on the internal surface of the soil. It appears, therefore, that hygroscopic moisture in air-dry soil varies with the humidity of the atmosphere and that equilibrium between them is maintained by means of evaporation from the surfaces of the soil particles and condensation from the enveloping atmosphere.

Movement of Capillary Water.—The inner capillary water, which occupies a transitional stage between the hygroscopic water and the outer capillary, moves slowly by diffusion in the colloidal matter. This film of moisture is much thicker than that of the hygroscopic moisture but is still too thin for ordinary capillary movement. The movement of the outer capillary water is influenced by the size of the soil particles, the structure of heavy soils, and their organic content. This movement is brought about by the surface tension of the water.

Effect of Size of Soil Particles.—In coarse-grained soils, such as sands and sandy and gravelly loams, the pore spaces are so large that the outer capillary water is held only in the sharp angles between the particles. The film of water probably is not continuous over the surfaces of these large particles except, perhaps, near the point of maximum capillary capacity. Because of the large pore spaces, capillary movement is appreciable only within a very short distance above the surface of free water. Since under ordinary conditions this point is some distance below the surface of arable soils, capillary movement may be regarded for all practical purposes as absent in these coarse soils.

In silt loams, in contrast, the size of the pores is optimum and water rises by capillarity to surprising heights from a free-water surface. Over a period of weeks, water in soils in glass tubes in the laboratory at the University of Illinois rose to heights of 8.5 to 9.5 feet from a free-water surface.[1] The soils used were silt loams that were very low in organic and colloidal matter. It is not necessarily true, however, that a similar rise of capillary water takes place in these or similar soils in the field.

Effect of Structure of Heavy Soils.—In clayey soils of single-grain structure, the pores are so minute that surface tension is incapable of overcoming the friction within the liquid and between it and the soil particles. At any rate, the rise of capillary water from a free-water surface in clay soils in tubes is not great, in fact, only a little more than 12 inches during a period of 90 days. In a well-granulated soil, however, somewhat more movement may be expected if the granules are of a size approximating that of coarse silt and very fine sand. As the water enters the spaces between the granules, the colloidal matter in them swells upon wetting. Under certain conditions, this swelling brings about compaction and reduction in the size of the pores and, therefore, decreases capillary movement of water in such soils.

Effect of Organic Content of the Soil.—Organic matter, like colloidal material, expands upon wetting and checks capillary movement in fine- and medium-grained soils. By means of its influence upon granulation of heavy soils, however, organic matter may improve capillary movement. Also, in coarse ones, particles of organic matter may occupy the large pores and thus in a measure aid capillarity. Under many, if not all, conditions, organic matter materially improves the water relations of essentially all kinds of soils.

The Mechanics of Capillary Movement of Soil Water.—A soil that is moderately well supplied with outer capillary water appears to have a continuous film of water about the soil particles. In a state of equilibrium, the film, theoretically, is of the same thickness over the surfaces of the particles. Located in the sharp angles between particles is a wedge of water. This results from the fact that the surface of the water tends to assume the same

[1] MOSIER, J. G., and A. F. GUSTAFSON, "Soil Physics and Management," p. 206, J. B. Lippincott Company, Philadelphia, 1917.

curvature between, as around, the particles. Thus, soil particles *A* and *B* in Fig. 25, having films of water of the same thickness, are brought into such position that their films coalesce. The sharp curvatures at *x* and *y* can no longer exist because of the tendency of the film to assume the same curvature at all points. The movement continues until the position shown by the solid line is attained. It should be appreciated that these film adjustments take place upward and downward as well as in the horizontal plane and constitute *capillary movement* of soil water.

When a light shower falls on comparatively dry soil, the water passes downward by gravity for a short distance or until this force can move it no farther. The surface soil, which is now well supplied with capillary water or has thick films, is in contact

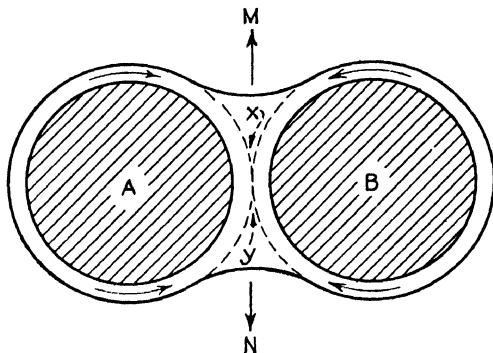



FIG. 25.—Movement of capillary water in the soil.

with drier soil below. In the drier soil the films are very thin, and a slow movement of water sets in from the thick to the thin films. As the thicker films become thinner, the movement proceeds more and more slowly. Although considerable time—months, perhaps—may be required, equilibrium with the drier soil below is eventually attained.

Farmers often take advantage of the beneficial effects of light showers on soils that are too dry and hard to plow. The rain may be insufficient to percolate to plow depth, but in the course of a few days the moisture penetrates below the plowline by capillarity. Thus, the soil is again rendered suitable for plowing, even though the soil may soon become too dry for the germination of fall-sown crops such as wheat and rye.

Temperature affects viscosity materially, it being but half as great at 25 as at 0°C. Even so, because of the lessened friction

that accompanies lowered viscosity, rise in temperature increases the rate of capillary movement.

Movement of Gravitational Water.—Water moves downward in soils in response to the pull of gravity; hence the designation *gravitational* water. The rate of movement of gravitational water (percolation) is influenced by the size of particles. In gravelly and coarse sandy soils, the pores are so large that water passes through them very rapidly. These soils, therefore, have good to excessive drainage and are dry, or droughty. They do not hold enough water to supply the needs of most crops during periods of low rainfall.

In contrast, the pores in such fine-grained soils as heavy silt loams, clay loams, and clays in a condition of single-grain structure are so minute that percolation through them is very slow indeed. This undesirable condition is changed by granulation through natural means and may be accomplished in time by the incorporation of organic matter. In granular soils, the size of the individual pore spaces between granules may compare favorably with the size of those in sandy loams and sands. Under these improved structural conditions, percolation takes place to a desirable extent in heavy soils.

Changes in temperature, because of their effect on the viscosity of the water, materially influence percolation. Soils drain slowly in early spring because of the low temperature of the soil and the consequent high viscosity of the soil water. The same situation prevails late in autumn. In some years, heavy rains come so late that the soil is full of water when it freezes. Owing to the high viscosity at temperatures approaching the freezing point, even sandy and gravelly soils hold water to the extent of almost complete saturation. Repeated freezing under these moisture conditions has been known to cause heaving in coarse soils to an extent not normally expected.

Evaporation of Water from the Soil.—Evaporation from the surface of moist soil is rapid, especially on bright, warm days under conditions of low relative humidity. Moreover, air movement increases evaporation still further and, indeed, greatly. Evaporation is rapid, so rapid, in fact, as to menace crop production in regions of low precipitation, such as the subhumid and semiarid areas. A quantity of rainfall that is sufficient for successful dry farming in North and South Dakota is inadequate in

Texas or other areas of high temperatures and low relative humidity. The presence of a crop on the land reduces the loss of water by direct evaporation from the soil.

At Ithaca, N.Y., during the years 1922 to 1929, the average rainfall during the 8 months of April through November was 21.5 inches. During the same period, the average loss by evaporation from a small free-water surface was 23.19 inches.

Later data obtained at Ithaca, N.Y., are given in Table 14.

TABLE 14.—RAINFALL AND EVAPORATION ON CALDWELL FIELD AT ITHACA, N.Y.*

Years	Rainfall, May through September, inches	Evaporation	Evaporation times rainfall
1932	15.72	25.18	1.60
1933	19.09	24.75	1.30
1934	19.14	29.08	1.52
1935	22.67	24.62	1.09
1936	11.27	30.36	2.69
1937	21.19	24.42	1.15
1938	18.17	26.50	1.46
1939	12.50	29.80	2.38
Average	17.48	26.83	1.57

* LELAND, E. W., unpublished data, Department of Agronomy, Cornell University Agricultural Experiment Station, Ithaca, N.Y.

Attention is called to the marked variations in rainfall for the 5 months, May through September, at Ithaca and also to the high evaporation during 1936, the year of lowest growing-season rainfall. During that year, the evaporation was 2.69 times the rainfall. This is in marked contrast to the preceding year, 1935, when the rainfall was the highest for these 8 years and the evaporation was low, both in total and in relation to rainfall. These data cover only a brief period; yet they represent a cool humid area reasonably well.

At College Station, Tex.,[1] in contrast, the evaporation from a free-water surface was 56.97 inches as an average for 17 years. At Balmarhea, the evaporation was 70.59 inches as an average

[1] KARPER, R. E., Rate of Water Evaporation in Texas, *Texas Agr. Exp. Sta., Bull.* 484, 1933.

for 14 years, the actual average annual precipitation there being 13.75 inches for that period, evaporation being 5.2 times the rainfall. At Dalhart from April through September, evaporation was more than 50 inches. According to Karper, the total annual loss of water by evaporation, as an average for 21 stations in Texas over the various periods of record, was 61.65 inches. Nearly two-thirds of the loss occurred during the 6 months, April through September. In the eastern and southeastern parts of Texas, rainfall exceeds evaporation, but in the drier areas evaporation from a free-water surface may be 4 to 5 times as great as the annual rainfall there. Under these conditions, considerable effort to reduce loss of water by evaporation appears to be well justified.

Effects of Water on Soil Temperatures.—Water in the soil serves as a regulator of its temperature. This regulation occurs in two general ways: (1) Water resists change in temperature to a greater extent than do soil materials. (2) The evaporation of water requires a relatively large quantity of heat. In addition, conduction and percolation exert some influence on the temperature of the soil.

It was shown on page 49 that the approximate weight specific heat of mineral soils is 0.2 and that of water is 1.0. From this it is clear that a given number of heat units applied to a unit weight of water effects but one-fifth as much change in its temperature as if applied to an identical weight of dry mineral soil. If a soil contains 20 per cent of water, its weight specific heat is 0.33.[1] In the spring, the soil is often saturated. In this condition, it is obvious that the heat normally available in early spring can raise the temperature of wet soils much less than that of well-drained soils of optimum moisture content. This helps to explain why well-drained sandy soils are "early" ones and why sandy soils are so highly esteemed for early vegetables.

Moreover, as shown on page 50, the evaporation of water from the soil greatly reduces its temperature. In early spring and late autumn, such reduction in soil temperature retards

[1] 1 gram of dry soil = 1 × 0.2 (specific heat) = 0.2
20 per cent = 0.2 gram of water
= 0.2 × 1 (specific heat) = 0.2, or a total of 0.4
0.4 ÷ 1.2 grams (weight of soil + water)
= 0.33, or specific heat of the moist soil

growth of crops. During periods of high summer temperature, on the contrary, evaporation tends to keep the temperature of the soil from going too high. Growth even of such hot-weather crops as melons, beans, and corn (maize) is retarded when the temperature of the soil or the atmosphere greatly exceeds the optimum (Table 7) for any particular crop. However, because loss of water from the soil during the growing season is seldom desirable, evaporation usually is not encouraged even for the control of soil temperatures.

Effects of Water on Aeration of the Soil.—For desirable natural aeration of soils, it is essential that the larger pore spaces be occupied by air and not by water. In the case of very wet soils, the effectiveness of the pores is reduced because much space is occupied by water. As the effective size of the soil pores is reduced, the ease with which an interchange of soil gases with the atmosphere takes place also is reduced. And saturated soils have no aeration. Since seeds require oxygen for germination and roots need oxygen for growth, it is obvious that any marked interference with aeration is distinctly detrimental to crops. The remedy for this condition is the removal of superfluous water from the soil by drainage (Chap. VI).

WATER OF SOILS IN RELATION TO PLANTS

Up to this point, the discussion of water has been concerned mainly with its relation to the soil. Its relation to plants and its function in plant growth will now receive attention.

As may be seen in the diagram (Fig. 24), hygroscopic water is not usable by ordinary plants. The film of water is held so tightly that plants cannot obtain it for purposes of growth. The inner capillary, like the hygroscopic, water is ordinarily unavailable for plant growth. It may, however, function as a regulator of temperature somewhat more effectively than does the hygroscopic water. Yet the quantity of inner capillary water in soils is often less than that of hygroscopic water.

The outer capillary water is used by ordinary crop plants. The broad middle section of the zone of outer capillary moisture is that which plants use for their best growth. This is the *optimum* water content, or optimum moisture zone. Everything feasible within the farmer's power should be done to maintain an optimum moisture content of the soil. Some measures for the control of

soil water are discussed in Chap. VI. In the lower zone of outer capillary water, the films may become so thin that the plant is unable to obtain sufficient moisture. As a result, temporary wilting may occur on bright, dry days. During cloudy weather and at night as evaporation from the plant is reduced, it recovers its normal condition. As the plant obtains less and less water, however, it wilts more and more and finally fails to recover. The moisture content has then been reduced to the zone of the *permanent wilting percentage*, often called the *wilting coefficient*. Permanent wilting and death of the plant follow; yet loss of water from both soil and plant may continue for some time.

At the other extreme of the capillary water, the films are very thick and so little space remains occupied by air that the water may be actually detrimental to ordinary crops. In fact, as the zone of maximum capillary capacity is approached, a very slight increase in amount of water or change in temperature may make it possible for some water to be pulled out of the soil by gravity. The *maximum capillary capacity* will then have been reached, beyond which water is subject to removal by gravity.

If gravitational water remains long in the soil, it is harmful to ordinary crops during the warm, active growing season partly because such water excludes the oxygen. And, moreover, it may encourage the accumulation of toxic substances in the soil. In addition, the water may inhibit the action of helpful soil organisms. Only water-loving plants, called *hydrophytes*, withstand the effects of gravitational water in the soil about their roots for any considerable length of time.

Water Needs of Crops.—The quantity of water used by plants for the production of 1 pound of dry matter is often called the *transpiration ratio* or the *unit water requirement.*[1] The water requirement is the water taken into the plant and given off during growth by means of transpiration and evaporated from the leaves and other parts of the plant (see page 94). This water should not be confused with that lost from soils by evaporation. The latter loss is not a part of the unit water requirement as ordinarily considered.

[1] While unit water requirement refers to the quantity of water transpired per unit of dry plant material produced, the term *total* water requirement may be used to include all the water required to produce a crop.

The water requirement per unit of dry plant material is influenced by two sets of factors, one having to do with the soil and the other being concerned with climate.[1] In addition a marked variation is noted between different types of plants.

Soil Factors.—The water requirement of plants has been studied with respect to soil conditions in many parts of the world. Extremely wet or very dry soil appears definitely to increase the water requirement of various plants. Soil texture, on the contrary, appears to have little effect. In other words, a given crop when grown on a sandy loam requires approximately the same quantity of water to produce 1 pound of dry matter as on a silt or a clay loam.

The water requirement per unit is higher on soils that are deficient in available plant nutrients than on those of high natural productivity. In fact, the fertilization of poor soils has been shown to reduce materially the unit water requirement. Moreover, the plant-nutrient solution from an untreated, unproductive soil may be lacking in nitrogen, phosphorus, or other needed elements, and such deficiency may materially increase the water requirement per unit of dry matter.

Climatic Factors.—Climatic factors markedly affect the quantity of water used by plants. Leaf and air temperatures and the relative humidity of the air exert a strong influence on the quantity of water required by plants. And as would be expected, unit water requirement is high if evaporation from a free-water surface is high. Moreover, warm, dry winds greatly increase evaporation from plants.

A given plant requires more water for the production of a unit of dry matter in a dry region than in one of higher relative humidity. This is shown in Table 15.

In general, unit water requirement bears a close relationship to the degree of deficiency in humidity. Peas required nearly twice as much water in Utah and Colorado as in Wisconsin. The normally high humidity at Rothamsted, England, and possibly high fertility, may explain the lower water requirements for crops there as compared with the requirements for identical crops in Wisconsin.

[1] BRIGGS, L. J., and H. L. SHANTZ, The Water Requirement of Plants, *Bur. Plant Industry, U.S. Dept. Agr., Bul.* 285, 1913.

TABLE 15.—WATER REQUIREMENTS FOR CROPS UNDER DIFFERENT CONDITIONS*
(Pounds of Water Needed for Each Pound of Dry Matter Produced)

Crop	Lawes,† 1850, Rothamsted, England	King,† 1892–1895, Madison, Wis.	Widtsoe,† 1909, Logan, Utah	Briggs and Shantz, 1913, Akron, Colo.
Wheat	235	...	546	507
Oats	...	541	...	614
Barley	258	388	...	539
Rye	...	...	...	724
Corn	...	350	386	369
Sorghum	...	...	...	306
Millet	...	...	...	275
Beans	214	...	...	728‡
Peas	235	477	843	800
Clover (red)	251	481	...	789‡
Clover (sweet)	...	...	...	709
Alfalfa	...	...	...	1,068
Potatoes	...	423	...	448
Sugar beets	...	...	497	377

* BRIGGS, L. J., and H. L. SHANTZ, The Water Requirement of Plants, *Bur. Plant Industry, U.S. Dept. Agr., Bull.* 285, p. 90, 1913.
† Quoted by Briggs and Shantz.
‡ BRIGGS, L. J., and H. L. SHANTZ, Relative Water Requirement of Plants, *Jour. Agr. Research*, Vol. III, p. 59, 1914.

Efficiency of Different Plants.—Briggs and Shantz worked with a wide range of plants in Colorado. On the basis of their data (Table 15), corn, sorghum, millet, and sugar beets may be regarded as being fairly economical in their use of water. Beans, peas, red clover, sweet clover, alfalfa, and rye are less economical. Wheat, barley, and potatoes on the basis of these data are intermediate and are not very economical in their use of water. The possession of root systems that can obtain large quantities of water may be an especially important consideration in the selection of crops for arid regions.

The total water requirement of crops is very large. A 50-bushel crop of oats, including 2,000 pounds of straw and stubble—based on King's figures, 541 pounds of water for 1 pound of dry matter—requires almost 9 inches of water. That for a 75-bushel crop of corn including about 4,000 pounds of cobs, stalks, and leaves is about 12 inches of water. For a crop of 3

tons of alfalfa including some stubble, based on Briggs and Shantz's unit water requirement of 1,068 pounds of water for this crop, the total yearly water requirement for alfalfa under irrigation is nearly 30 inches. These quantities of water appear very large, but they give an idea of the need for conserving water for crops in humid as well as in arid areas.

Benefits of Capillarity to Crops Limited.—Some years ago, it was believed that the rise of water by capillarity was an important factor in supplying crop plants with water between rains. In medium-sand or gravelly soils, the pores are so large that the surface tension of soil water cannot bridge them. Capillary action in these coarse soils consequently is very slight, the lift from a free-water surface in such soils being in fact but a few inches. Many soils have a compact, impervious clay or silt stratum 15 or 20 inches below the surface. In such material, the pores are very small and, upon wetting, any colloidal matter present swells and essentially closes the openings. Under these conditions, capillary action cannot be of much benefit to growing crops. In peat soils (Chap. XIX), also, capillary action is limited to very short distances and to a zone very close to the free-water table. Here again, therefore, the benefits of capillary action are distinctly limited.

In heavy clay soils, large cracks form in dry periods. During soil survey work, the author observed cracks of 2 to 3 inches in width. These wide cracks are sometimes not more than 10 or 12 inches in depth. Below this depth, moist clay was found in heavy soils. Under these conditions, it appears that capillary action is unable to carry water from the moist soil below to the surface at a rate that can prevent excessive shrinkage.

In open, coarse silt loams and very fine sandy loams, capillary action is much more effective in lifting water than in fine- or very coarse-grained soils. And it is probable that crops are benefited in some degree by this upward movement of water. If the water table is within 6 feet of the surface in alkali soils soluble salts may be carried upward in the soil solution and deposited at the surface by evaporation. Moreover, capillarity is effective within short distances and may be helpful under favorable conditions.

In spite of this bit of contradictory evidence, it is believed that capillarity is not important generally in supplying crops with water. No doubt, plants are benefited somewhat by capillary

action in soils that have a favorable physical make-up. Plants have developed their enormous root systems which with the tiny root hairs present to the soil an enormous total surface. This may be interpreted as the provision by means of which plants may obtain water instead of simply accepting it as capillary action delivers water to them.

Questions

1. Distinguish between the forms of soil water.

2. Discuss the important factors that influence the amount of capillary water in arable soils.

3. What is the relative importance to crops of the movement of the different forms of soil water?

4. Discuss the evaporation of water from soils.

5. State the effect of soil water on soil temperatures.

6. How does soil water affect aeration of the soil?

7. Discuss the relative unit water requirement of crops.

8. In what ways do soils affect water requirements of crops?

9. How does the climate of a region influence the quantities of water used by crops?

10. Discuss the relative efficiency in the use of water by different types of crop.

CHAPTER VI

THE CONTROL OF WATER IN THE SOIL

The importance of water in its relation to the maintenance of favorable physical conditions of the soil with the need for optimum moisture conditions for plants has been discussed in Chap. V. The control of water in the soil may now be given consideration.

THE MANNER OF LOSSES OF WATER

Water is lost from the soil in various ways, the principal ones being by transpiration from plants, by evaporation from the soil, by runoff, and by percolation (Fig. 26).

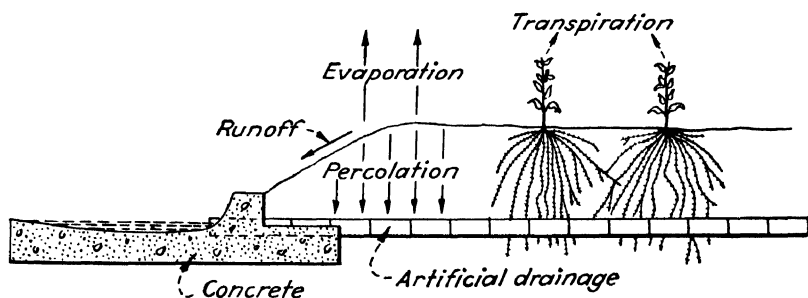



FIG. 26.—Losses of water. Part of the rainfall evaporates from soil, plant, and other surfaces, along with the water of transpiration from plants. Some water percolates into the soil for the use of crops or becomes a part of the natural ground water. When the top of the ground water is too near the surface plants suffer unless such water is removed by artificial drainage. Tiling is a good method. (*Adapted from E. W. Lehman and T. A. Pitzen, Illinois Agr. Exp. Sta., Circ.* 439.)

Transpiration.—The life processes by which plants give off water, mainly from their leaves, is called *transpiration.* In daytime, especially when the sun is shining, water exuded by plants evaporates quickly and large quantities of it pass from the plant to the atmosphere in this way. A necessary function of plants, this type of loss from crops is to be encouraged rather than discouraged. However, transpiration of water from weeds is dead loss and should be reduced to a minimum by controlling weed

growth. It must be remembered that loss by evaporation of the water that comes up through the plant should not be confused with evaporation from the soil or evaporation of dew or rainfall from plants and inanimate objects.

Evaporation.—Evaporation takes place from the surface of moist soils as well as from free-water surfaces, but with some difference in rapidity. In humid areas, the loss of water by evaporation usually is not regarded as serious during periods of normal rainfall. In droughty periods, however, loss of water from the soil by evaporation is as harmful to crops in humid as in arid or semiarid regions. Even brief periods of a shortage of water, particularly if accompanied by high temperatures, can reduce crop yields materially. This condition is frequently encountered with disastrous effects on yields in the dry areas that are subject to high temperatures and strong winds.

Runoff.—In many parts of the United States and in other sections of the world, as well, rain falls more rapidly than the soil can absorb it. Under these conditions, water obviously runs off over the surface of the soil. This loss of water, referred to as *runoff*, is an entire loss to the soil, to crops, and to the farmer. Not only is water lost, but the runoff water from bare or only partly covered fields carries away plant nutrients, organic matter, and some of the body of the soil itself. Even though the soil be well covered with vegetation, runoff water carries away soluble nutrients and organic matter. These losses, however, are much smaller from soils that are covered by vegetation than from bare, cultivated ones. Slater and Carleton[1] report average annual losses of 0.24 to 1.38 tons of organic matter an acre over a period of 6 years from cropped land at Clarinda, Iowa. The highest loss was slightly greater at Bethany, Mo. Sod lost little organic matter. Being very light in weight, fragments of organic matter readily float on water and consequently are easily carried away. Detailed ways of controlling the losses of runoff water and of soil are given in Chap. IX.

Percolation.—Part of the water that falls on the soil as rain and snow passes downward through the surface into the subsoil. Eventually some of this passes into the deep substratum and later into openings in the bedrock. In both of them, as reser-

[1] SLATER, C. S., and E. A. CARLETON, The Effect of Erosion on Losses of Soil Organic Matter, *Proc. Soil Science Soc. Amer.*, Vol. 3, pp. 123–128, 1938.

voirs, it constitutes the ground water. This is the supply of water for wells and springs and that which feeds streams during periods between rains.

Percolation takes place so readily in gravelly and sandy soils that they fail to hold sufficient water for many crops, particularly in dry periods. Compacting these light soils reduces the openings between the soil particles and thus encourages retention of water in the topsoil. Such soils need additions of fresh organic matter,

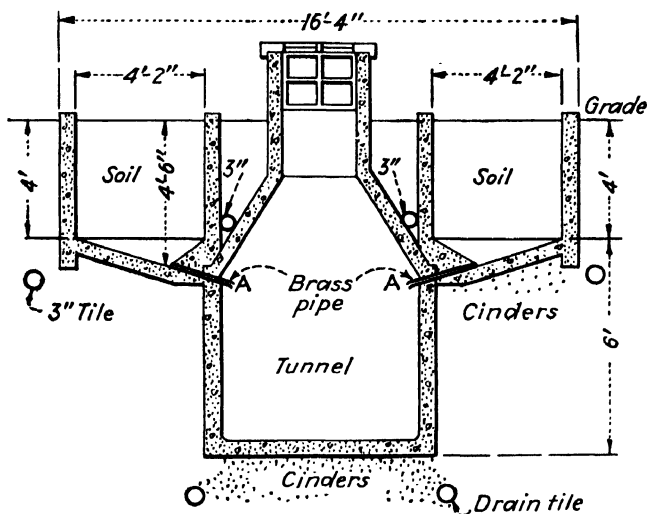



FIG. 27.—Lysimeters at Cornell University. The soil containers are 4 feet 2 inches square and 4 feet deep. The funnel-shaped bottom of the containers is filled with coarse sand. The drainage water comes into the tunnel through the brass pipes *A* from which the water is collected in suitable vessels. (*Adapted from T. L. Lyon and J. A. Bizzell, Cornell Univ. Agr. Exp. Sta., Mem.* 12, *p.* 8, 1918.)

but in order to produce beneficial effects additions need to be made regularly over the years.

At the other extreme are the soils that have an impervious stratum within 8 or 10 inches below the surface and others that have such a stratum 20 or 24 inches below it. In periods of heavy rainfall, the downward movement of water is severely restricted under these soil conditions. At such times, water may stand in depressions and to some extent on level areas and do much damage to crops.

In contrast, percolation into open, retentive silt loams and clay loams that are well stocked with organic matter is highly

desirable. Such soils retain much water in the surface and subsurface strata for use by crops. In soils of ideal physical make-up, percolation into the subsoil leaves in the topsoil a quantity of water that approaches the optimum moisture content for crop plants. That the surface water and that over and above the optimum should pass away as runoff and by percolation, respectively, is desirable. When percolation is too slow after heavy rains, free water remains in the soil which is said to be *waterlogged*. This condition is highly unfavorable for most crops. Wherever possible, reasonably rapid removal of surplus water is desirable for normal growth of crops.

The percolation of water through Dunkirk silty clay loam, a heavy lake-laid soil, was studied in lysimeters (Fig. 27) over a period of 15 years at Ithaca, N.Y. The average annual rainfall for the period was 32.52 inches. The data on percolation are given in Table 16.

TABLE 16.—AVERAGE ANNUAL PERCOLATION THROUGH BARE AND CROPPED SOIL DURING 15 YEARS*

Cropping	Average annual percolation	
	Inches	Rainfall, per cent
None (soil bare)	21.62	66.43
Cropped each year	15.67	48.15
Difference	5.95	18.28

* LYON, T. L., J. A. BIZZELL, B. D. WILSON, and E. W. LELAND, Lysimeter Experiments—III, *Cornell Univ. Agr. Exp. Sta., Mem.* 134, p. 14, 1930.

Bare soil was compared with that under crops from 1910 to 1924. It is interesting to note that as an average over this 15-year period the percolation through the bare soil was two-thirds of the rainfall. In comparison, the loss from the cropped soil was slightly less than one-half of the rainfall. In round numbers, cropping reduced the loss of water by percolation nearly one-fifth. It was noticeable that the bare soil became more compact after the first 5 years, but no such compacting was noted in the cropped soil. Compacting of the bare soil would have been expected to diminish the rate of percolation, but it did not reduce the total loss of water.

Undoubtedly percolation takes place more freely through the soil in these lysimeters than through the same depth of soil in its natural undisturbed condition in the field, for the soil in the lysimeters rests on a bed of free-draining sand. In contrast, the top 4 feet of this soil in the field rests on slow-draining clay subsoil. Moreover, the lysimeter walls extend up above the soil so that no rain water is lost as runoff. Consequently, more percolation would be expected than from similar soil under field conditions.

It should be borne in mind that at Ithaca, N.Y., the soil is frozen a large part of the time from late November or early December until late March or early April. In contrast with this condition is the one at the Rothamsted Experiment Station at Harpenden, England, where but little freezing of the soil occurs. There much of the rainfall is of low intensity in contrast with the high-intensity showers at Ithaca. The Rothamsted data for percolation are given in Table 17.

TABLE 17.—DRAINAGE THROUGH 5 FEET OF UNCROPPED CLAY LOAM, ANNUAL AVERAGE FOR 42 YEARS, ROTHAMSTED EXPERIMENT STATION, HARPENDEN, ENGLAND*

Months	Rainfall, inches	Drainage, inches	Drainage as percentage of rainfall
December–February	6.77	5.58	82.4
March–May	5.96	2.11	35.4
July–August	7.83	1.82	23.2
September–November	8.29	4.50	54.2
Mean total	28.85	14.01	48.5

* HALL, A. D., "The Book of Rothamsted Experiments," p. 22, E. P. Dutton & Company, Inc., New York, 1917.

Particular attention is called to the very high loss (82.4 per cent) of the precipitation during the months of December, January, and February, a period of little plant growth and little evaporation from the soil. During June, July, and August, the period of greatest crop growth, the loss (23.2 per cent) is but slightly more than one-fourth as great as during the winter months. This period of the year (June to August) at Rothamsted also is the time of greatest evaporation from the soil. The mean loss of water by percolation at Rothamsted (48.5 per cent) is

strikingly similar to the loss from the cropped soil (48.15 per cent) at Ithaca, N.Y.

Losses of Plant Nutrients.—As already indicated, water dissolves plant nutrients in the soil. Unless plants use all these nutrients, they may be lost whenever rainfall is heavy enough to bring about percolation or drainage through the soil. Though plant-nutrient losses are somewhat difficult to study, much work has been done on this problem not only in the United States but in Europe and in other parts of the world. In fact, much of the work in this country has followed the general pattern of the experiments started in England more than three-quarters of a century ago.

Lysimeter studies in this country have been made in Tennesse, Illinois, Michigan, and New Jersey, at both Geneva and Ithaca in New York and at other experiment stations.

Because much variation is found in the data obtained in lysimeter studies under different conditions of soil and crop management and fertilization, the interpretation and use of such data require good judgment.[1]

Two soils, Dunkirk silty clay loam and Volusia silt loam, were studied over a period of years in the Cornell lysimeters. The Dunkirk silty clay loam is a productive, fine-grained soil that was formed from soil material deposited in glacial-lake water. This soil is relatively well supplied with calcium and magnesium. The Volusia silt loam was formed by the weathering of shale together with a slight addition of foreign material as the result of feeble glaciation. This soil is markedly deficient in basic materials.

[1] The Cornell lysimeter studies are reported in Lysimeter Experiments, by T. L. Lyon and J. A. Bizzell, *Cornell Univ. Agr. Exp. Sta., Mem.* 12, 1918 (this publication contains a complete description of the construction and layout of the lysimeters, and a résumé with bibliography of the lysimeter work done in Great Britain, Germany, Sweden, France, and Switzerland); Lysimeter Experiments—II, by T. L. Lyon and J. A. Bizzell, *Cornell Univ. Agr. Exp. Sta., Mem.* 41, 1921; Lysimeter Experiments—III, by T. L. Lyon, J. A. Bizzell, B. D. Wilson, and E. W. Leland, *Cornell Univ. Agr. Exp. Sta., Mem.* 134, 1930; and Lysimeter Experiments—IV, by T. L. Lyon, and J. A. Bizzell, *Cornell Univ. Agr. Exp. Sta., Mem.* 194, 1936. Parts of the work are reported in various other publications. Additional references to lysimeter work are given by T. L. Lyon and H. O. Buckman in "The Nature and Properties of Soils," pp. 146–153, The Macmillan Company, New York, 1937.

The losses of plant nutrients from these soils as found in the lysimeter studies are shown in Table 18.

TABLE 18.—ANNUAL LOSSES OF NUTRIENTS IN DRAINAGE WATER FROM CROPPED AND UNCROPPED SOILS*

Soils and cropping condition	Annual losses, pounds to the acre					
	N	P_2O_5	K_2O	CaO	MgO	SO_3
Dunkirk silty clay loam:†						
Uncropped	69.0	Trace	86.8	557.2	104.4	132.5
Cropped in rotation	7.8	Trace	69.1	322.0	73.2	108.5
Grass, continuous	2.5	Trace	74.5	364.0	83.1	111.1
Volusia silt loam:‡						
Uncropped	43.0	Trace	77.3	452.6	68.3	88.5
Cropped in rotation	6.6	Trace	68.9	350.5	46.7	82.0

* See footnote, page 102.
† Data for 10 years.
‡ Data for 15 years.

From the data in Table 18, several points may be noted: (1) The loss of nitrogen was heavy from the uncropped bare soil. In comparison with this loss, that from soil which produced a rotation of crops is moderate. And the loss of nitrogen from soil under grass was relatively very small. (2) Phosphorus was lost only in traces from these soils under these conditions. This, in view of the low phosphorus content of soils, is a particularly favorable condition. (3) Potash was lost in fairly large quantities from all of the conditions studied, although some conservation of it was brought about by cropping, grass apparently being less effective in this regard than the average crop grown in rotation. (4) Calcium was lost in extremely large quantities under all conditions. Considerable amounts of magnesium, also, passed out of the soil in the drainage water; but these amounts are much smaller than those of calcium. (5) Sulphur, expressed as the trioxide, was lost in quantities somewhat larger than those of potash.

It is notable, and indeed fortunate for man, that cropping the soil reduces so markedly the losses of potassium, calcium, and magnesium in drainage as compared with leaving the soil without crop.

From such data as these, one can readily surmise how heavy are the losses of nutrients suffered by soils that lie fallow throughout the growing season. In the dry-farming areas where fallowing is practiced generally, summer rains are often of the thundershower type and, therefore, produce much runoff and some leaching. The salts are leached downward, but they are not necessarily lost completely from the subsoil. In compensation, however, the dry-farming soils developed under conditions that produced an abundance of available plant nutrients that have not been leached away. In fact, lack of moisture and not lack of plant nutrients usually determines crop yields in the drier regions.

In Table 19 is given a comparison of the average annual losses of nutrients from a cropped soil and the quantity of nutrients in the produce of an acre of average rotation crop.

TABLE 19.—COMPARISON OF THE AVERAGE ANNUAL LOSSES OF NUTRIENTS BY LEACHING FROM DUNKIRK SILTY CLAY LOAM CROPPED IN ROTATION, WITH NUTRIENTS USED IN THE PRODUCTION OF AN AVERAGE CROP IN A ROTATION

Cropping condition	Pounds to the acre			
	N	P_2O_5	K_2O	CaO
Leached from cropped soil	8	Trace	69	322
Used by average rotation crop	44*	22	50	21

* The average amount of nitrogen used by crops is influenced materially by the length of the rotation and the ability of the leguminous crop to obtain nitrogen by means of the nodules on their roots.

The data for nutrients used by crops are based on actual composition and normal yields. Drainage losses of nitrogen and phosphorus from the cropped soils are relatively slight in comparison with the needs of crops. The losses of potassium, calcium, magnesium, and sulphur, in contrast, are heavy in comparison with actual consumption of nutrients by crops. On the basis of these data, the excessive loss of calcium is particularly notable.

The value of lysimeter data is based on the perfectly reasonable assumption that a close similarity of composition exists between the water percolating through the soil, whether it be in a lysimeter or in the field. Moreover, within reasonable limits of

comparison as to depths and time of contact between soil and water, similar composition of drainage water may be expected from tile, shallow springs, and lysimeters.

THE BENEFITS DERIVED FROM ARTIFICIAL DRAINAGE

Wet soils usually lack many of the physical properties that favor the growth of plants. The removal by artificial means, called *drainage*, of the free, or gravitational, water from the top 2 to 4 feet or more of soil produces many changes in the physical condition of the soil that are beneficial to most plants of economic importance. As would be expected, the improvement in soil conditions produced by drainage is reflected in a material increase in crop yields.

Improvement in Stability.—Wet soils are notably unstable in part because the excess water separates the soil particles. Removal of the water permits the particles to form contact with each other. The water which acted as a lubricant between the particles is reduced, and the soil assumes a condition of desirable stability. Closely related to this condition is the situation in peat soils. During formation, such material floats in, or is at least distinctly buoyed by, the water. Readjustment of the constituent materials after clearing, plowing, draining, and cultivating the peaty soil brings about distinct settling and marked lowering of the surface of such soils.

Encouragement of Granulation and Aeration.—Wet soils frequently are puddled or run together, a condition that is decidedly unfavorable for the growth of crops. Drainage permits the surface of the soil to dry out, and this in turn tends to bring about granulation of heavy loams and silt loams, clay loams, and clays. The presence of a goodly supply of well-decayed organic matter materially aids the process of granulation. A soil whose granules are relatively stable permits the free percolation of rain water into the soil. Moreover, because the granules are so much larger than the individual clay and silt particles, the granular soil has fewer but much larger pores than the soil of single-grain structure. In the granular condition, therefore, the interchange of gases between the soil and the atmosphere takes place with ease. Because plant roots require oxygen and inoculated legumes must have nitrogen about their roots in order to fix this element, aeration of the soil is essential for suitable

Fig. 28.—Effect of drainage on available water and growth of plants. In the undrained condition the roots are restricted to the immediate surface soil in the wet early spring. In the drained soil, in contrast, the roots occupy the entire area drained by the tile. In the drained area, therefore, the crop can draw on a deeper stratum and thus obtain more water. Moreover, as the undrained soil dries out later in the season the roots that have not extended into the subsurface are incapable of obtaining sufficient water and their growth consequently is restricted. (*Courtesy of J. R. Haswell.*)

growth of crops. Though carbon dioxide aids in rendering certain nutrients available to plants, its presence to the exclusion of oxygen and nitrogen is distinctly detrimental to many crops.

Increase in Water Available to Crops.—The removal of excess water by drainage actually increases the quantity of water available to plants. At first thought, this statement may appear paradoxical. Reference to Fig. 28 may help to clarify this point. Here is a condition in which the soil is wet to within 8 inches of the surface in the spring and whenever prolonged rainfall occurs. Moreover, the water table drops slowly until the growing season is well under way. In this situation, the feeding roots of plants are restricted to approximately the surface 8 inches.

Near by, tile has been installed at a depth of 30 inches. After making proper allowances, it is fair to say that the crop has the upper 24 inches, at least near the tile, in which its root system may develop and expand. These plants, therefore, have a root zone three times the thickness of that occupied by the plants in the undrained soil. As the season advances, the water table drops and thus deepens the root zone. It is conservative to state that the plants on the drained soil have at least twice the depth of root zone and consequently twice the total reservoir upon which to draw for the capillary water needed for growth. Later in the season, the water table in the untiled soil may drop to the level of the tile; but even so the root system is unlikely to extend itself to that depth in the undrained soil, and the result is a permanent handicap to the crop. Moreover, unfavorable or toxic conditions are likely to develop in the waterlogged soil that require considerable time and treatment for their complete alleviation.

Rise in Temperature of the Soil.—The effect of water on soil temperature was discussed in Chap. V. There it was shown that water has a weight specific heat of about five times that of dry soil, the figures being, respectively, 1.0 and approximately 0.2. Five times as much heat is required, therefore, to effect a given change in the temperature of water as of soil. Moreover, the application of heat, as in sunshine, is partly used in vaporizing some of the water. Owing to the enormous quantity of heat required to change water to vapor, the evaporation of water is distinctly a cooling process. Since, therefore, the drained soil contains no free water, in fact, has much less total water than the

undrained soil, the drained soil warms up in the spring considerably earlier than does the waterlogged one. For this and various other reasons, a well-drained soil is much preferred over an undrained one, particularly for early spring crops.

Aid to Bacterial Action.—Many of the organisms that aid in producing conditions in the soil that are favorable for crop plants do their work only in the presence of atmospheric oxygen. Since oxygen is largely excluded from waterlogged soils, it is obvious that these helpful organisms cannot function in such soils until the soils have been drained and aerated. Moreover, certain organisms live and work in the water. Not only does this group break up plant nutrients that had been prepared by the helpful group, but the harmful ones may produce substances that are toxic or poisonous to crops. Here, then, is a further reason for the removal of excess water from the soils on which economic plants are being grown.

Reduction in Heaving.—Heaving of soils results from the expansion that accompanies the freezing of water in them. That water expands markedly upon passing from the liquid to the solid state is well known. The most serious heaving occurs where a source of water exists under the surface of the soil. In this condition, water under the surface freezes, perpendicular crystals being formed. As the water in contact with the bottom of the crystals changes to ice, it is added to the lower end of the crystals which thus grow from below. This may continue indefinitely unless the temperature rises or the supply of water is exhausted. The force of freezing water is practically irresistible. Familiar examples of its force are the bursting of automobile radiators and other water pipes.

Alternate thawing and freezing of the surface inch or two of soil that is frozen below cause serious injury to crops such as winter grains, grasses, and such deep-rooting legumes as sweet and red clover and alfalfa (Fig. 29).

Thawed soil in winter is often saturated. If the upper inch or two thaws, it usually is very wet and upon freezing expands irresistibly. Deep-rooted plants are sometimes broken off at this point in this way. The result is the loss of the crop.

On the other hand, if freezing occurs under the surface and the crystals of ice grow from wet soil below, plants such as the deep-rooted legumes are lifted much as an object is lifted by a

jackscrew. Removing the source of water by drainage greatly reduces, but may not entirely prevent, heaving by these methods.

Lessening of Erosion on Slopes.—That the surface of heavy soils upon thawing is very wet, in fact is often a thin mud, is a familiar phenomenon. On slopes, this thin mud often flows in response to gravity, with a considerable down-the-slope movement of the immediate surface soil as the result. In case of heavy

Fig. 29.—Alfalfa heaved out of the soil. Freezing heaves out alfalfa, sweet and red clover, and other deep-rooting crops much the same as it does steel stakes or fence posts. Its force is essentially irresistible. Most plants are killed by being heaved to this extent. (*Courtesy of S. V. Holt.*)

rains on such partly thawed soil, the loss of the thawed part may be complete. In fact, on soils left bare over winter, this type of loss of soil is critical. Again, drainage may serve as a partial remedy under favorable conditions.

DRAINAGE SYSTEMS

Farmers early noted the detrimental effects of water standing on soils for considerable periods. Crops were killed, or the yield was greatly reduced. The use of furrows and open ditches

probably dates far back in the world's unwritten agricultural history. It is recorded that drainage, the artificial removal of water from land, was practiced in the Nile Valley as early as 400 B.C. The Romans in Cato's time used stones and bundles of faggots in trenches.[1] Near the middle of the seventeenth century, Blith advocated a similar method of drainage in England. Smith in Scotland in 1823, nearly 175 years after Blith, actually established underdrainage of soils. He is reported to have used trenches 30 inches deep, in the bottom of which he placed 3-inch stones to a depth of 12 inches, the trenches being placed 10 to 40 feet apart.

Two types of drain are in general use: the *open* and the *closed*, or *covered*, drain. Each type has its place and under certain conditions of soils, crops, and rainfall serves its purpose better than the other.

Open Drains.—By *open drains* are meant furrows or open ditches of variable depths and widths. The open furrow may be produced by plowing a field in narrow lands, the backing furrow and the "dead furrow" both being made in the same places for several years. This accomplishes two things: a definite ridge is built up, and a distinct open furrow which has been given a slight slope or fall is produced. Water flows off the ridge into the furrow and thus passes off the land.

In areas of nearly level land or of slow-draining, tight, or impervious subsoils, the open furrow is relied upon to effect quick removal of surface water. In many areas of peat and muck, owing to lack of fall, open ditches are rather commonly used especially in the deeper organic soils.

In many situations, open ditches are used because of the large quantities of water to be removed. Obviously, one reason for the use of open ditches for draining fairly large areas of relatively flat land is the prohibitive cost of removing the excess water in any other way.

Open ditches possess obvious disadvantages. The mere dead furrow can be crossed with all the ordinary farm implements; but even small permanent ditches cannot be crossed conveniently, and therefore they divide the area traversed into separate units. Since these units must be worked separately, such ditches usually

[1] WIER, W. W., "Soil Science," pp. 261–262, J. B. Lippincott Company, Philadelphia, 1936.

increase costs of production. Open ditches require regular care in order that they may function effectively after heavy rains,

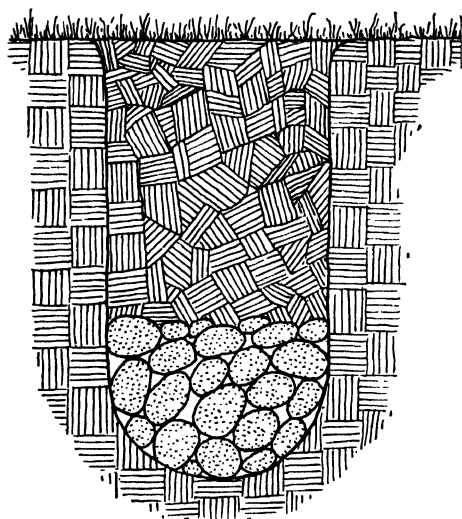



FIG. 30.—Early underdrainage with stones. The lower third of the trench was filled with cobblestones. Drains of this sort have been uncovered recently in New York that have apparently been functioning for nearly three-quarters of a century.

especially during the growing season. These ditches ought to be kept clear of in-washed debris at all times.

Closed Drains.—The early closed drains consisted of faggots or loose stones (Fig. 30) in the bottom of trenches. Stone drains, in which a definite opening was maintained, were used many years ago (Fig. 31). Drains of this type have served their purpose for many years. Mole[1] drainage has been practiced to advantage in Great Britain and to some extent in the Midwest.

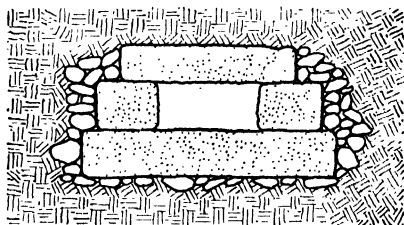



FIG. 31.—Stone drain in cross section.

[1] In mole drainage, a circular opening through the soil is made by an implement of the Killefer type (Fig. 55) by using a ball or circular-ended shoe. Water enters the opening and flows to the outlet much as it does in tile.

The earliest burnt-clay tile was laid by hand. It consisted of a clay slab on which was laid an inverted U-shaped tile. This is the kind that John Johnston, a Scotchman, imported from England. These handmade tile, the first to be used in the United States, were laid in 1835 by Johnston on his farm of heavy clay soil on the east side of Seneca Lake about 2 miles south of Geneva, N.Y. Being the true pioneer, John Johnston has been called

FIG 32—Plaque commemorating the hundredth anniversary of the laying of the first tile in the United States in 1835 by John Johnston near Geneva, N. Y. (*Courtesy of B B. Robb*)

"the father of tile drainage" in this country In commemoration of the hundredth anniversary of the laying of the first tile in this country, a bronze plaque attached to a 30-ton boulder was unveiled with appropriate ceremonies in October, 1935 (Fig. 32). The monument is located on what was a part of the original Johnston farm near Geneva.

The tile-making machine was brought to the United States in 1848, and tile factories were established for making burnt-clay

tile. More recently, tile has been made of concrete, also. In laying tile, there is some opening between them. It is through these joints that water enters the drains and is thus removed from the land. Some years after the development of the tile-making machine came the invention of the trench-digging or tiling machine (Fig. 33). Much tiling had been done previously, but this machine together with experimental and educational work on drainage gave great impetus to tiling. This is shown by the fact that 63,500,000 acres in this country had been drained (largely with tile) up to 1930, according to Ayres and Scoates.[1]

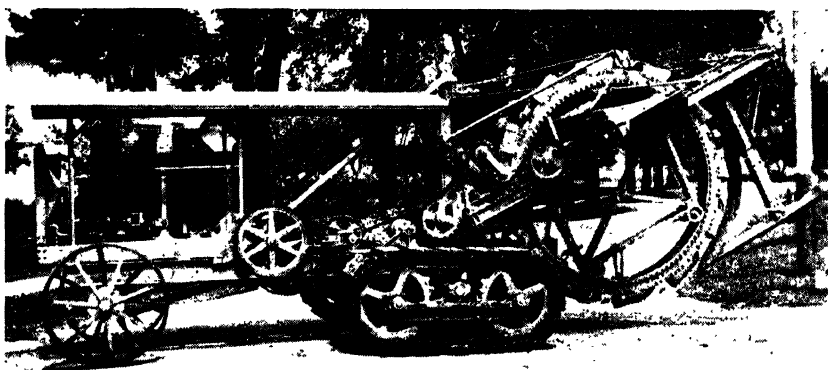



FIG. 33.—A modern ditching machine. Tiling received an additional impetus upon the development of this ditching machine. The digging wheel with its cutting buckets, or scoops, is lowered to cut a ditch of the desired depth. The tile may be laid directly back of the machine. (*Courtesy of Buckeye Traction Ditcher Co.*)

Many additional acres are in need of drainage in order that they may be operated economically and may produce the yields of which they are capable.

A number of systems of tile drains enjoy conventional names such as *natural, cutoff, herring bone,* and *gridiron* (see Figs. 34, 35, and 36). Numerous other systems and combinations of them are in use. In fact, except in large, nearly level areas, the gridiron and herringbone systems are seldom used without at least slight modifications.

Obviously, space cannot be given here for an extended statement of details of installing drainage systems. This must be

[1] AYRES, Q. C., and DANIELS SCOATES, "Land Drainage and Reclamation," p. 9, McGraw-Hill Book Company, Inc., New York, 1939.

left to books and bulletins on that subject[1], but a few brief suggestions may be helpful.

Ordinarily, the main tile should follow nature's own drainage lines or streams that naturally occupy the lowest places. Straight lines of tile are usually most effective. It is often better to dig a deep trench through a moderate rise in the land than to make a sharp curve in order to run the tile around it. Where they are absolutely necessary, curves should be long and smooth.

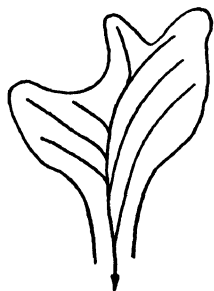



Fig. 34.—Natural system.

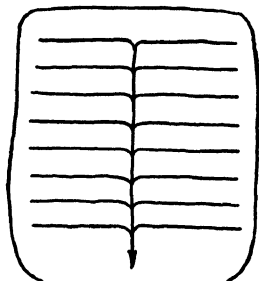



Fig. 35.—Herringbone system.

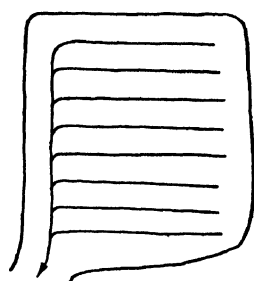



Fig. 36.—Gridiron system.

The grade, or slope, in the tile should be uniform. At any rate, dips ought to be avoided for the obvious reason that the carrying power of water is greatly reduced (Chap. I) with any flattening in the slope. Any sediment in the drainage water is deposited in a section of reduced slope. Reduction in effectiveness and eventually complete clogging follow such deposition. Laterals require a steeper slope than does the main tile. Laterals ought to join the main at an acute angle, never at right angles, and preferably from above the main if sufficient fall is available.

[1] Ayers and Scoates, *op. cit.*

Powers, W. L., and T. A. H. Teeter, "Land Drainage," John Wiley & Sons, Inc., New York, 1922.

Robb, B. B., and F. G. Behrends, "Farm Engineering," Chap. VII, John Wiley & Sons, Inc., New York, 1924.

Elliott, C. G., "Engineering for Land Drainage," The Macmillan Company, New York, 1912.

Jeffery, J. A., "Textbook of Land Drainage," The Macmillan Company, New York, 1916.

This partial list will supply much of the information needed for the actual installation of drainage systems. Many of the state experiment stations and extension services and in addition the U.S. Department of Agriculture have published valuable information on this topic.

This arrangement tends to accelerate the flow in the main and to keep it free of sediment.

Only porous soil material should be used to fill the trench over the tile.

Outlets should be protected against rodents, for if allowed to enter the larger ones may clog the drain. Heavy hardware cloth or iron rods across the end of the outlet tile may be used for this purpose. In addition, outlets require protection against erosion. Stones, concrete, and vegetation may be used for protecting outlets.

The size of tile needed depends on the slope, the size of the area to be drained, the intensity of rainfall to be expected in the area, the rate of percolation into the soil, and the sensitiveness of the

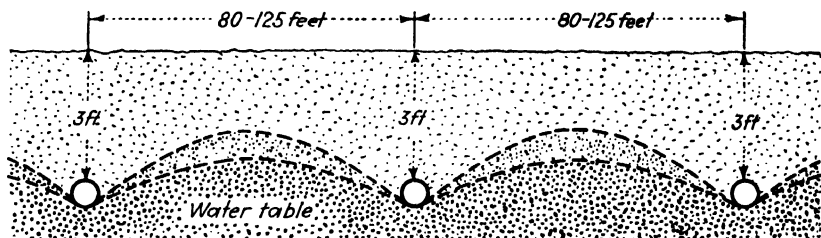



Fig. 37.—Relation of soil to water table. The top of the heavily shaded area represents the water table in average free-draining soils. The upper dotted line represents the water table in moderately slow-draining soils in which the lines of tile must be closer together than in easily drained soils. (*Adapted from E. H. Lehman and T. A. Pitzen, Illinois Agr. Exp. Sta., Circ.* 493.)

crop grown to the presence of gravitational water about its roots. The best distance between lines of tile is closely associated with factors that govern the size of the tile needed. Obviously, in soils on which sensitive crops are grown much of the time, the lines must be laid close together in order that the excess water may be quickly removed. In fine-grained soils that lack stable granulation or those whose subsoil is so compact that the pores are too small to permit relatively free movement of water, the lines of tile need to be closer together than in free-draining soils (Fig. 37). Tables for the size of tile needed will be found in the books and bulletins already referred to, but decision as to distance between lines as well as depth of tile will be determined by such considerations as the soil itself, the rainfall, and the need for quick removal of excess water. And here judgment based upon experience with,

and observation on the behavior of, different soils will aid greatly in reaching the right decision.

IRRIGATION

In sections where the average rainfall is of sufficient amount and well distributed throughout the growing season, it is possible to produce good yields of crops on most soils. In the drier areas where the average annual rainfall is less than 20 inches, the practice of irrigation,[1] or the application of additional water, is much more common. In the semiarid and arid regions, the rainfall, including the snow, is usually concentrated during the winter months, and very little occurs during the summer. Therefore, it is essential to practice irrigation in these areas in order to ensure good crop growth and to produce a greater variety of crops.

Importance of Irrigation in Arid Areas.—In studying the development of agriculture in the arid areas, one finds that the most rapid advances were made where crops were irrigated. Irrigation has been a means of producing greater and more certain yields.

Most of the irrigated land in the United States lies west of the hundredth meridian which extends from North Dakota to the western part of Texas. In this area, approximately 20 million acres are at present being irrigated. Israelsen estimates that "probably 50 per cent of the ultimate irrigable area yet remains nonproductive because of lack of water."[2]

The extent of land irrigated is rapidly increasing. In regions of low rainfall, every farmer should give some thought to the

[1] Additional information is found in the following publications:

HUBERTY, M. R., and J. B. BROWN, Irrigation of Orchards by Contour Furrows, *California Agr. Ext. Ser., Circ.* 16, revised 1932.

BROWN, J. B., The Contour Check Method of Orchard Irrigation, *California Agr. Ext. Ser., Circ.* 73, 1933.

FORTIER, S., Practical Information for Beginners in Irrigation, *U.S. Dept. Agr., Farmers Bull.* 864, 1932.

GROSS, E. R., Growing Crops under Sprinkling Irrigations, *Proc. and Papers First Intern. Congress Soil Science*, Vol. 4, p. 623, 1928.

VEIHMEYER, F. J., and A. H. HENDRICKSON, Essentials of Irrigation and Cultivation of Orchards, *California Agr. Ext. Ser., Circ.* 50, 1932.

SCOFIELD, C. S., and F. B. HEADLEY, Quality of Irrigation Water in Relation to Land Reclamation, *Jour. Agr. Research*, Vol. 21, pp. 265–278, 1921.

[2] ISRAELSEN, O. W., "Irrigation Principles and Practices," pp. 2–4, John Wiley & Sons, Inc., New York, 1932.

principles underlying the successful application of irrigation water.

The quality or salt content of the water used for irrigation should be ascertained. Information can usually be obtained from the state agricultural experiment station. The continued use of irrigation water having a high content of certain salts, such as those of sodium, or even relatively small amounts of boron will in time produce a toxic condition in the soil. This condition is discussed further in Chap. XI.

Irrigation Systems.—In all systems of irrigation, an attempt should be made to obtain a uniform distribution of the water and a sufficient penetration into the soil in order that crops may root deeply. If the water is applied sparingly, the surface soil dries out within a few days after irrigation, and, unless water is applied again, the plants start wilting. One should examine the soil 2 or 3 days after an irrigation to determine whether or not sufficient water has been added to moisten the entire root zone. On the other hand, it is wasteful to apply so much water that it penetrates far beyond the root zone. In overirrigation, the available nutrients in the surface soil are leached down beyond the reach of the roots. Moreover, the cost of applying this excess water is in many instances of considerable magnitude. However, if soils contain alkali, it may be advisable occasionally to overirrigate in order to wash these injurious salts down and out of the root zone of the soil.

Sprinkling Systems.—The most common method of applying irrigation water to small areas is by means of a sprinkling system. This system is used to a limited extent for orchard and field crops. Care must be taken in spacing the individual sprinklers since it is difficult to wet the area uniformly if they are placed too far apart and if there is a low water pressure. Also, when strong winds are blowing, certain portions of the irrigated area will receive much more water than others. On the other hand, if the sprinklers are placed too close together, some of the area is doubly irrigated and the soil receives excessive quantities of water. Many different types of sprinkler head are being manufactured. Some that are placed on lawns are installed in a permanent way so that the grass can be mowed without interference. In nurseries and orchards, they are placed on supports above the ground at such heights and locations that they do not interfere

FIG. 38.—Typical overhead irrigation installation in an avocado orchard. For convenience in cultural operations, the stands are placed in the trees. (*Courtesy of Robert W. Hodgson.*)

FIG. 39.—Irrigating late spring canning spinach with an overhead sprinkler system. A tractor furnishes power for the pump. (*Courtesy of G. W. Scott.*)

with the usual field operations of plowing or cultivation (Fig. 38).

Portable types are in use that employ pipes with special locking devices for connecting the sections quickly and making the joints watertight. The pipes containing the sprinkler heads can be moved from one part of the field to another by attaching more pipes or by laying them on the surface of the soil in another direction. The method described has been used primarily for annual crops, such as peas, spinach, and sugar beets. On most of the

FIG. 40.—The furrow system of irrigation commonly used on terraces. The length of the furrows should not exceed 300 feet. (*Courtesy of Robert W. Hodgson.*)

overhead sprinkling systems, a turning union is installed so that the spray of water can be directed more efficiently with respect to variations in the wind direction and water pressure (Fig. 39).

In some areas, a porous canvas hose is laid on the surface of the soil; and when the water is turned into it under slight pressure, the water slowly percolates through the hose onto the soil.

Furrow Irrigation.—The most common method of irrigation on hillsides is to apply the water to the surface of the soil in furrows or small distches running along the contour (Fig. 40). If the water is permitted to run down the slope at right angles, there is danger of washing away a considerable portion of the

valuable surface soil when a large flow is used and insufficient water percolates into the soil. If but a small stream is used, only a narrow strip of soil is moistened. Orchards are very often planted on hillsides because there is usually less danger from frost in such places than on the lower lying valley soils. The practice of irrigating by means of contour furrows in these hill-

Fig. 41.—Special equipment for irrigating hillside plantings. The distributor shown above is used where the pipe line passes down a ridge with the furrows sloping each way from it. The distributor is jointed so that it can be raised vertically to be out of the way of cultural operations. (*Courtesy of Robert W. Hodgson.*)

side orchards has increased during recent years. Water is distributed to the furrows by means of ditches, flumes, or pipes, provided with openings which can be closed after sufficient water has entered the furrows (Figs. 41 and 42).

The type of soil and degree of slope will determine the grades upon which the tree rows are to be placed. Where the soils are shallow and the grade is steep, fewer furrows are needed than where the soils are deep. In the valley lands where there are mature orchards having deep soils, it is not uncommon to find

FIG. 42.—Distribution of water from flume. (*Courtesy of M. R. Huberty and J. B. Brown.*)

FIG. 43.—An underground pipe line with outlets as shown in the foreground and extending down the slope allows water to be taken from it on both sides. (*Courtesy of M. R. Huberty and J. B. Brown.*)

farmers using six or more furrows for each row of trees. Special attention should be given to the length of the furrows, for in porous soils with long furrows and a small head of water excessive penetration is accompanied by leaching of plant nutrients near the head of the furrow. In contrast, at the lower end insufficient water may be applied for the trees (Fig. 43). More frequent irrigations are necessary on sandy than on clayey soils, and

FIG. 44.—Irrigating lettuce beds before seeding, in the Sacramento Valley, Calif. Water enters the furrows from the head ditch. A piece of shook, a length of pipe, or some other device is used to regulate the flow. *(Courtesy of the Irrigation Division, College of Agriculture, University of California, Davis, Calif.)*

shallow-rooted crops must be irrigated more frequently than those that are deep rooted.

Most vegetable crops, in sections where irrigation is necessary, are planted on raised beds. This arrangement aids in the application of the water. These beds are usually about 20 inches in width, and the irrigation furrows between the beds are of approximately the same width. These furrows are made, when the soil is fairly dry, with a variety of implements, such as the lister, or moldboard plow, and the crop beds are smoothed with a sled or

rake. The seeds are planted in rows near the edges of the beds, and the irrigation water in the furrows subirrigates the beds. For most soils, it is not advisable to irrigate the top of the beds, for upon drying out they bake to such an extent that the young plants are unable to force their way through (Fig. 44).

Flood Irrigation.—Where there is an abundant supply of water and large areas are to be irrigated, some system of flooding is commonly used. The water may be diverted from large ditches to land that is fairly level. When the slope of the land is irregular, however, it is necessary that some leveling and checking be

FIG. 45.—Apricot orchards irrigated by the basin method. (*Courtesy of A. H. Hendrickson.*)

done in order that the water may be controlled. All grading operations should be performed when the soil is fairly dry in order to avoid puddling. A puddled or packed condition reduces the rate of penetration of water and consequently limits development of a deep root system. Various methods of checking are used and are designated as the *basin, contour, border* or *strip* methods. In the basin method, used in some orchards and vineyards, basins are made and the water is run from one basin to another (Fig. 45). The contour check system is used on uneven land by constructing levees on the contour, usually with an interval in elevation between the contours of 0.2 foot. Another levee is constructed

at the end of the contour levees, thus making an enclosed basin. The distance between these levees varies with the degree of slope, quantity of water available, nature of the crop, and height of the levees (Fig. 46).

The levees, or ridges of soil, can be constructed by various types of tillage implements. In fields where a crop such as alfalfa is being grown, it is necessary that the height and the width of the levees be such that mowers can be operated over them. In

Fig. 46.—The modified basin method of contour irrigation. (*Courtesy of M. R. Huberty and J. B. Brown.*)

orchards, however, the levees can be higher and may have steeper sides. In many districts where alfalfa is the main crop, the border, or strip, method, is now used in preference to the others, because by this method the water can be applied more uniformly without a great deal of labor. In making border checks, the land between the levees should be graded so that it is fairly level along a line running at right angles from one levee to the next, and the basin between two levees should have a gradual slope parallel to the levees. The width and length of the checks must be varied with the soil type and the volume of irrigation water available.

With a volume of 450 gallons of water per minute, the checks in a sandy soil are usually made from 20 to 30 feet wide and not more than 300 feet long. In a clay soil with the same volume of water, the checks can be 30 feet wide and in many instances can be twice as long as in a sandy soil. A careful study must be made of the types of soil in a field, accurate grades of the surface determined, and the volume of irrigation water, commonly called "head of water," ascertained before the checks are constructed. This is essential if one wishes to avoid the mistake that many have made of having the checks too long, thus causing a condition of over-irrigation in the upper end of the check and only a light irrigation in the lower portion.

In some districts where the water is not readily absorbed by the soil or where it has a tendency to bake, a corrugation method of irrigating a crop, such as alfalfa, is used. Sufficient grading is done to produce a gentle slope; then furrows or corrugations are made down the slope at intervals of about 20 inches. Only small streams of irrigation water are run in the furrows.

Subirrigation.—Soils lying in depressions where the subsoil is impervious and where water is supplied by seepage from higher lands or by springs have a high water table. Shallow-rooted crops are usually planted in such localities, and the height of the water table is controlled by means of ditches and pumps.

A widely fluctuating water table is not considered to be the best condition for good root development; it is very important, therefore, to regulate the drainage system properly. The sprinkling system is used to some extent on subirrigated lands, and only light applications of water are made to supply the surface roots. The deeper roots simultaneously are supplied with moisture from below. Lines of tile have been laid in some areas, and water has been run into them. Seepage at the joints subirrigates the soil. Roots may find their way into these tiles and decrease their efficiency after a short time. These roots can, of course, be periodically removed by various tile-cleaning rods and brushes, but in many cases the tile lines settle irregularly and thus become useless.

Importance of Irrigation in Humid Areas.—During recent years, crops in the humid areas of this country have suffered from long periods of little or no rainfall during the growing season. These instances are so numerous and so distressing and so fresh

in the minds of many persons as to need no recounting. An instance or two will suffice. During the entire growing season (May through September) at Ithaca, N.Y., in 1936, the total rainfall was only 11 inches (Table 14), less than one-half of the normal amount and in 1939, 12.5 inches. The 8-year average for these months was 17.5 inches. Nearly every year drought occurs somewhere in humid areas.

Although the average rainfall in humid areas is ample for the production of good crop yields, it is during these long periods of drought, particularly at a critical stage of growth that some form of irrigation would aid greatly in stabilizing the total yield of crops. Irrigation is obviously more essential in the production of human-food crops than of animal-feed crops, partly because most vegetable crops on mineral soils are grown on early, open, quick-draining ones. Naturally, these cannot be highly retentive of moisture and at the same time be early soils. In fact, many desirable vegetable soils, other than peats, are actually droughty ones. For the high-return vegetables, a particular type of irrigation, largely by means of pipes or porous hose, is being practiced on an increasing scale. Overhead systems have been widely used (Fig. 39).

Many farms possess streams or locations for farm ponds. By damming a stream, a "head" of water can be produced so that the water may be led by gravity through either pipes or open ditches to vegetable and other crops downstream. Owing to the high porosity of some valley soils, piping will conserve water and is better than conducting it through open ditches. In some places, it may be necessary to pump the water from a stream or reservoir on a lower elevation to the soil to be irrigated. Under some conditions this may be accomplished with the farm tractor during the night, in order that it may serve its normal uses on the farm in the daytime. As the advantages of irrigation during droughty periods in humid areas become more fully appreciated, the ingenuity of farmers and gardeners may be depended on to develop economical means of irrigation whenever it is needed.

Provision for thorough drainage should be made in connection with irrigation in humid areas. Otherwise, heavy rainfall following soon after irrigation might cause serious damage to crops that are sensitive to excess water in the soil.

DRY FARMING

Dry farming is the practice of crop production without irrigation in regions of low rainfall. It is accomplished chiefly by adopting certain forms of tillage that produce the utmost conservation of the rainfall and by growing crops that are to a certain extent drought enduring. It has been most successful in those sections which normally have an annual rainfall of 10 to 20 inches and in sections where the rainfall cannot be supplemented by means of irrigation because of prohibitive costs.

The distribution of the annual rainfall is fully as important as the total. A section receiving 13 inches of rainfall during winter and spring, with frequent showers during the spring months, will generally have a higher yield than it would have if the total rainfall were higher and if most of the rain fell during the winter months.

The essentials for dry farming[1] are soil conditions that permit absorption and retention of the limited rainfall and the proper selection of crops.

Soil Conditions.—It is essential to have deep soils. The minimum depth of permeable material cannot be definitely stated, but those profiles which consist of 4 feet or more of good soil are to be preferred to those which are shallower (Fig. 47).

Unfavorable profile conditions, such as presence of bedrock close to the surface, heavy clay subsoil, hardpan layer, high water

[1] Additional information may be found in the following publications:

KELLOG, C. E., Soil Blowing and Dust Storms, *U.S. Dept. Agr., Misc. Pub.* 221, 1935.

BRAKEN, A. F., and GEORGE STEWART, A Quarter Century of Dry-farm Experiments at Nephi, Utah, *Utah Agr. Exp. Sta., Bull.* 222, 1930.

CHILCOTT, E. C., The Relation between Crop Yields and Precipitation in the Great Plains Area, *U.S. Dept. Agr., Misc. Circ.* 81, 1927.

DILLMAN, A. C., The Water Requirements of Certain Crop Plants and Weeds in the Northern Great Plains, *Jour. Agr. Research* (U. S. Dept. Agr.), Vol. 42, pp. 187 238, 1931.

OGAARD, A. J., Summer Tillage Implements, *Montana Agr. Ext. Ser., Bull.* 79, 1926.

MATHEWS, O. R., and JOHN S. COLE, Special Dry-farming Problems, Soils and Men, Yearbook of Agriculture, 1938, pp. 679–692, U.S. Department of Agriculture.

GILMORE, J. W., Crop Sequences at Davis, *California Agr. Exp. Sta., Bull.* 393, 1925.

table, or coarse-textured subsoil, all restrict the development of deep root systems. The "hardpan" layer referred to is the naturally cemented horizon that is usually formed at depths to which the normal rainfall penetrates. It should not be confused with the plow pan formed at the depth of tillage when soils are cultivated while too moist. Many crops, normally shallow rooted when growing in the humid areas with a well-distributed rainfall during the growing season, develop deeper roots when planted in the dry-farming areas that generally have little rainfall during the summer months.

FIG. 47. — A desirable profile for dry farming, in Utah. This soil has a uniformly fine-grained profile. It is not too well drained nor does it have any impervious layers. (*Courtesy of D. S. Jennings.*)

The water-storage capacity of the soil determines whether the rainfall will be held in the surface 4 feet of soil or whether it will percolate to depths beyond the reach of plant roots. Percolation is most pronounced in the coarse-textured soils, and it is primarily in sections receiving a fair supply of rainfall during the growing season that such soils can be successfully utilized. Soils varying in texture from fine sandy loam to clay lose less water by percolation than sandy soils. Many dry-farmers prefer the finer textured soils, such as the clay loams and clays.

Soils that contain an excessive amount of soluble salts, commonly called "alkali," should not be dry-farmed, for it is very difficult, and in many cases impossible, to grow the usual crops on them.

Dry-land Crops.—The crops which succeed best under limited rainfall are those which can adjust themselves to the climatic and soil conditions prevailing in the dry-farming areas. Certain varieties of grain may grow well under humid conditions and fail in a drier climate where dry farming is practiced. Wheat is one of the most common grain crops raised, and a variety of wheat, such as the durum, has proved profitable in some dry-farming sections of the United States. This wheat was introduced from

FIG. 48.—Kafir, a grain sorghum. This grain sorghum thrives under dry-farming conditions and produces good yields of grain. (*Courtesy of Soil Conservation Service, U.S. Dept. Agr.*)

Russia where it had been grown successfully for many years in the drier areas. Corn, dwarf milo maize, kafir (Fig. 48), rye, barley, peas, potatoes, cotton, and forage grasses are produced in many of the dry-farming districts. Other crops have proved profitable, but those mentioned cover the greatest acreage. Varieties of different crops are being tested in the dry-farming belt through careful experimental work by agronomists and others, and the most promising ones are finally recommended. Some have been found to be more drought resistant than others because they become partly dormant and in that condition require little soil

moisture. Moreover, varieties have been found that mature in less than the normal period, and these varieties are highly desirable.

The heavier rate of seeding that is used in the humid or irrigated sections is not suitable for dry-farming areas. By reducing the rate of seeding, a better crop is ensured.

Over a long period, lower yields are obtained where the same crop is grown continuously than where a system of crop rotation or summer fallow is practiced. In some secions, a rotation of a crop such as wheat with an intertilled crop such as corn is used; in others, wheat is grown for 3 years, and then the land is left in fallow for one season. Many trials have been made in the western United States to ascertain the best systems of rotation for the various districts. In some instances where livestock is produced in conjunction with grain farming, higher yields are obtained. Keeping certain fields in pasture for a few years and returning the farm manure to the soil helps to maintain or increase the fertility of the soil, particularly during periods of high rainfall.

Tillage Practices.—Erosion caused by the wind is one of the greatest hazards in the dry-farming areas. For this reason, the farmer should practice such forms of tillage and cropping as will reduce wind erosion to a minimum. During the years of abnormally low rainfall and high summer temperatures, the soils become exceedingly dry and are subject to wind erosion. During the spring (March to May) of 1934 in the western part of the United States, much of the dry-farming area received only about 30 per cent of the normal rainfall. The dust storms during that year were of great intensity and caused considerable damage to growing vegetation as well as to the soil. Young plants were completely destroyed, and the fertile surface soil was removed and deposited several hundred miles away. The texture and structure of soils determines to a great extent their erodibility by winds. The sands, because of their loose structure, are more readily moved than heavier soils. On the other hand, some clay soils, upon drying, break up into aggregates lighter in weight than individual grains of sand and therefore are also easily moved by the wind.

Tillage methods should be practiced that will produce a small cloddy rather than a finely pulverized condition. The lister

(Fig. 53) which throws the soil both ways is frequently used to make ridges at right angles to the prevailing winds, thus reducing the tendency toward soil blowing. When the lister is used for certain crops such as maize, the seed is planted in the furrow. After the grain has germinated, subsequent cultivations move soil back into the furrow. The growing plants then help to hold the soil in place.

Strip cropping is practiced to advantage in some areas. Where the prevailing winds are from the west, strips about 150 feet wide, are run north and south. Alternate strips are seeded while the intervening ones are fallowed (see Chap. IX).

The practice of keeping the soil free of vegetation during an entire crop season is termed "summer fallow." Some farmers disk the stubble land in the summer and then seed the same area the next fall or spring. Others do not seed the land but permit the weeds to grow and refer to these systems as "fallow." Most authorities are of the opinion that the only successful fallow is clean, weedless fallow.

Some farmers "summer fallow" a certain acreage each year because they have found, particularly where the average annual rainfall is low, that they generally obtain a good yield following the year of summer fallow. If the whole acreage is cropped each year, there is real danger of crop failure during an unusually dry year. Summer fallow can therefore be considered a safeguard against total crop failure. Where the rainfall is low, it is possible to store part of it in the soil from one season to the next by means of summer fallow. However, some of the soil moisture is always lost by evaporation and through weed growth. Killing the weeds by cultivating as soon as the heavy rains are over, and then later cultivating again if another vegetative growth starts, saves from one-third to one-half of the rainfall. Thus, in a section with an average annual rainfall of 10 inches, it may be possible to store about 5 inches in the soil. The crop seeded after the summer-fallow year would have the benefit not only of the normal 10 inches of rainfall but also of the 5 inches stored in the soil from the previous year. This means that only one crop can be harvested in 2 years. In regions receiving less than 10 inches of rainfall annually, attempts have been made to "summer-fallow" 2 out of 3 years. This, however, is usually hazardous, because the cost of keeping land in summer fallow for 2 years is high.

Ten inches of annual rainfall, or slightly more, appears to be the lower limit of successful dry farming where summer fallow is practiced in alternate years.

Where the annual rainfall is about 18 inches, the main value of a summer fallow is not to store water in the soil but rather to make plant nutrients more readily available. If tillage for the control of weeds during the summer-fallow year is started early, the soil organic matter has an opportunity to decay while the soil moisture and temperature conditions are favorable. Decay makes more soil nitrogen available for the next crop than where continuous cropping is practiced. The use of fertilizers instead of fallowing might be profitable in some situations.

In dry farming, only such tillage methods should be followed in the particular district as have accomplished a useful purpose over a period of years. Excessive tillage not only increases the cost of crop production but in many instances pulverizes the soil too finely.

The methods used in the different sections vary with the type of crop, kind of soil, and climatic conditions. In the northwestern part of the United States, it is considered good practice to leave the stubble in the field because it holds the snow against drifting and aids in increasing the amount of moisture in the soil when the snow thaws in the spring. In the southwestern part of the country, some farmers till the soil immediately after harvest but turn the stubble under only partly so that the soil is left in a coarse, granular condition. This practice aids in keeping down late weed growth, reduces wind erosion, and leaves the soil in an absorptive condition for the winter rains.

With certain row crops, such as corn, it is sometimes necessary to cultivate shallow occasionally in order to reduce weed growth. It is no longer considered good practice, however, to cultivate primarily for the purpose of forming a soil mulch. The value of a soil mulch for conserving moisture has been overestimated, and the consensus of opinion is that the main value of cultivation in well-drained soils is for the control of weeds. Persistent cultivation in the absence of weeds destroys roots of the crop and makes the soil aggregates so small and loose that wind erosion may take place. Also, when the first rains fall after the dry period, water does not readily penetrate what is essentially a dusty surface layer.

The time when the land should be plowed has received considerable attention. Because of varying climatic conditions in the dry-farming areas, however, no one definite time is recognized as being the best for all areas. Fall plowing is practiced in some sections and spring plowing in other places. The depth of plowing has also received considerable attention, and the tendency in many sections is to vary the depth from about 5 inches in sandy loams to 8 inches in clay loams. Subsoiling is a practice of questionable value and, in general, is less practiced than formerly. Some authorities believe, nevertheless, that subsoiling deserves more trial on small acreages.

Use of Fertilizers.—Some investigators seriously question the use of certain fertilizers, particularly those containing nitrogen, in dry-farming areas because of low moisture content of the soil. The addition of the nitrogen may stimulate growth to such an extent that the soil moisture available would be insufficient to carry the crop to maturity.

The best way of determining the type and amount of fertilizers to use is by field trials over a period of years. The cost of such fertilizers, including their application, must be considered in connection with any increase in yields so that the question of whether their use is economical or not can be ascertained. It must always be kept in mind in dry farming that rainfall is the limiting factor, yet some soils may be low in available nutrients.

Questions

1. How is water lost from the land?

2. In what manner may undesirable losses be controlled?

3. Discuss the importance and means of control of losses of plant nutrients in drainage water.

4. What are some of the important benefits of artificial drainage?

5. How may drainage lessen losses of the soil itself?

6. Outline briefly the history of drainage.

7. What is the acreage already drained and the approximate area in the United States still in need of drainage?

8. Under what conditions is each type of drainage preferred?

9. Indicate the need for irrigation and the area in which it is practiced generally.

10. Discuss the important methods of irrigation.

11. Discuss irrigation in humid areas.

12. What is dry farming, and where is it practiced in the United States?

13. Discuss the important considerations with respect to soils, crops, and tillage practices in dry farming.

CHAPTER VII

TILLAGE OF THE SOIL

In the early days when man gathered the fruits of the wild tree and vine as he found them and while his roving herds sought feed wherever it could be found, he gave little thought to tillage of the soil and even less to possible tillage implements. Later, man established a more or less permanent abode and found plants, the products of which he greatly desired. Then he set about making conditions more favorable for these particular plants. In other words, he attempted to reduce the competition between

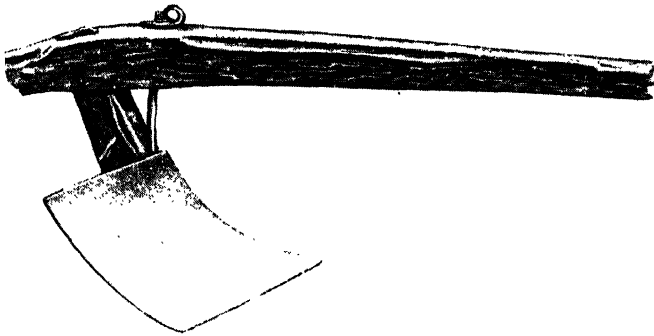



FIG. 49. Early John Deere plow. This plow is one of the first three made by John Deere in 1837. This implement is preserved in the Smithsonian Institution in Washington, D. C. (*Courtesy of John Deere, Moline, Ill.*)

the wanted or *crop* plants and the unwanted or *weed* plants. At first, no doubt, this early tillage was all done by hand with the aid of primitive wooden implements. Some centuries later after the development of metalworking, steel implements came into use (Fig. 49). Over the years, man has devoted and still is devoting many hours of hard labor to tillage operations before and after planting his crops.

PURPOSES OF TILLAGE

Under the term *tillage* are grouped all the ways of loosening, turning, stirring, and even compacting the soil. No historical

statement can be attempted here, interesting as that might be. There is space only for the present-day viewpoint and methods.

Loosening the Soil.—Because the ordinary crop plants do not thrive in soils that are hard or in poor tilth, farmers go to great expense of time and power to loosen them. This is accomplished mainly by means of the various forms and types of plow; by the disk harrow, in part; and in a measure by the recently developed rototiller and, in some areas, by deep-tilling machines of which the Killefer is representative.

Covering Crop Remains.—If such crop remains as stalks of corn, cotton, and broom corn, and if trash of low value is left on the surface, such trash interferes with the preparation for and cultivation of crops. Material of this kind being highly carbonaceous decays slowly, especially if left on the surface. For the foregoing reasons, these and other coarse leftovers from crops are plowed under. Covering them completely is usually desirable in the more humid areas. When they are covered, the organisms of the soil bring about their decay during the season. Such residues are thus turned to a useful purpose.

From the standpoint of the control of the corn borer, all stalks and other coarse materials should be plowed under as early in the spring as conditions permit. Complete coverage with soil of all the cornstalks is essential for even fairly good control of this pest of corn and other crops.

Conserving Moisture.—It has already been pointed out that loose soils take up more water and absorb it more rapidly than do compact ones. In compact soils, the pores are small in comparison with those in loose soils of similar texture. Under many conditions, soils lack sufficient pore space for the retention of as much water as is desirable. This is particularly true in the drier areas, even though the soils of dry climates do not ordinarily become so compact as soils often do in humid climates. Much of this compaction in moist areas is brought about by heavy rains and by the normal settling of wet soils.

Moreover, rain water runs off from compact soils very readily. In contrast, loose, newly plowed soils take up water quickly and thus hold it against loss over the surface. And as water is retained, so also are organic matter, plant nutrients, and, in considerable measure, the soil itself.

Controlling Weeds.—Weeds compete successfully with crops for both moisture and plant nutrients. Certain weeds are annuals, some biennials, and others perennials.[1] Plowing aids in the control of the biennial and annual weeds, particularly. All types of tillage, especially seedbed preparation, aid in the control of annual weeds. Methods of controlling weeds are dealt with in the closing paragraphs of this chapter.

Aeration of the Soil.—Nearly all tillage operations effect aeration of the soil to some extent. By *aeration* is meant the bringing about of an exchange of the gases in the soil with those of the atmosphere. Turning the soil with a moldboard or disk plow facilitates aeration to a marked degree. To varying extents, harrows, seeders, and cultivators help to aerate the soil. Rollers, alone, do not aerate the soil but instead expel air and gases. Owing to the fact that seeds need oxygen for germination and roots need it for growth, the replacement of carbon dioxide in the soil with fresh air to supply oxygen is essential for satisfactory growth of crops.

PLOWS AND PLOWING

Many implements are needed and used in the various tillage operations. The type of implement used varies with the kind of tillage to be accomplished. Obviously, an entirely different implement is needed for loosening the soil from that used for surface cultivation of intertilled crops.

Plows.—Plows are used for loosening the soil and for covering trash. Various types of plows are used according to the degree of turning of the soil desired.

Moldboard Plow.—The moldboard plow (Fig. 50) is the most commonly used implement for loosening the soil in humid areas. For cutting the side of the furrow slice, the coulter, the jointer, or the combined coulter-jointer may be used (Fig. 51). These devices are especially useful in the plowing of tough sod. The jointer turns the soil at the land side of the furrow slice over on it.

[1] Annuals grow and reproduce from the seed in one season. Foxtail, pigweed, and lamb's-quarters are examples. Biennials germinate and grow throughout one season and produce seed the following year. Mullein, bull thistle, and cockle are examples, although cockle may be regarded as a winter annual. Perennials, once established, grow from the root year after year. Examples are morning-glory, black bindweed, Canada thistle, quack or couch grass, and milkweed.

Fig. 50.—The moldboard plow. This two-way, two-horse implement may be used for regular plowing and is particularly useful for plowing sloping lands. By the use of this plow the ordinary dead furrow may be avoided. Complete covering of trash is desirable in humid areas. (*Courtesy of John Deere, Moline, Ill.*)

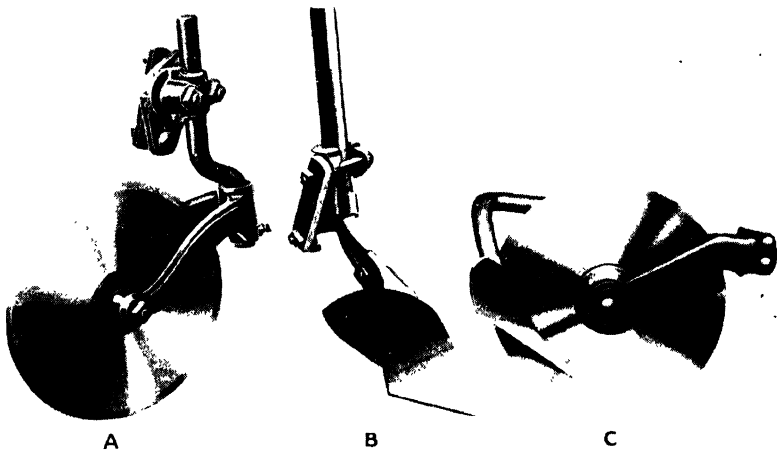



Fig. 51.—*A*, the rolling coulter; *B*, the jointer; *C*, the combined coulter and jointer. (*Courtesy of International Harvester Co.*)

When sod is thus turned, no grass is left in a position to grow even in wet seasons. Three fairly distinct types of moldboard are in use.

1. The "sod" moldboard has relatively little curvature because little is needed for turning tough sod. Such sod is turned by this moldboard with little pulverizing of the furrow slice. This condition facilitates the preparation of a seedbed.

2. The "general-purpose" moldboard has more curvature than the "sod" moldboard and serves well for general plowing. It works better, however, on light, than on tough sods, the latter being turned too much and left in a kinky rough condition, which

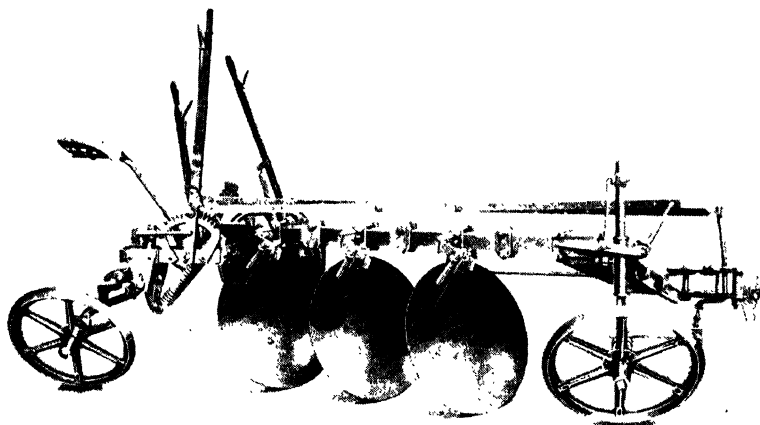



FIG. 52.—The disk plow. (*Courtesy of International Harvester Co.*)

makes seedbed preparation of stiff sods difficult. If all plowing on the moderate-sized farm must be done with a single implement, the general-purpose moldboard is to be preferred.

3. The "stubble" moldboard has a sharper curvature than the others. It pulverizes and turns the furrow slice more than the others do, an accomplishment that is desirable for small-grain stubble and for soils that have relatively little vegetation on them. Since such soils have become compacted over winter, they are in need of being thoroughly pulverized in order that a good seedbed may be produced at least expense.

Disk Plow.—The disk plow (Fig. 52) is used in dry climates because it does not pulverize the soil so completely as do the moldboard plows. A pulverized condition is undesirable in

semiarid and arid regions because of blowing of finely pulverized soils. Moreover, this plow may be adjusted to set the furrow slice on edge with stubble exposed more or less between the

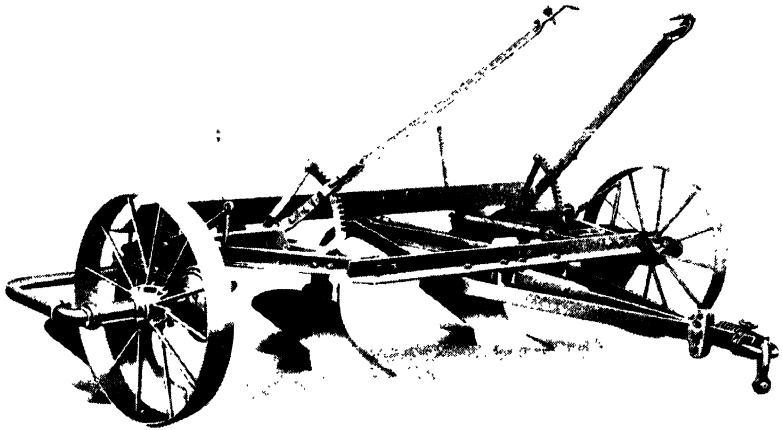



Fig. 53.—The lister. (*Courtesy of International Harvester Co.*)

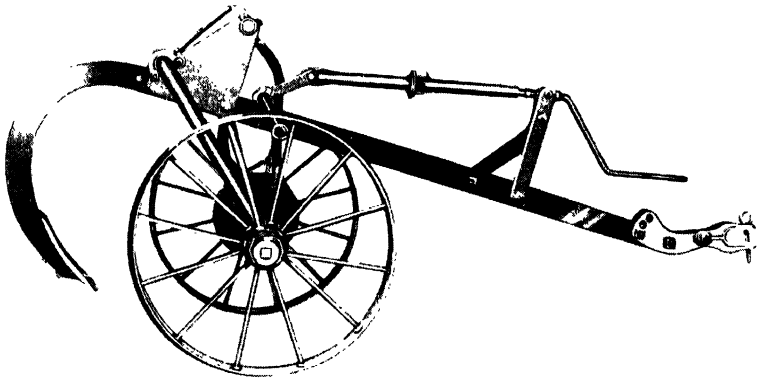



Fig. 54. The tractor subsoiler. When the beam is let down into position, the point loosens and lifts the soil in the bottom of the furrow without throwing any of it out or mixing it with the surface soil. (*Courtesy of the Oliver Farm Equipment Company.*)

furrow slices. This coarse material along with a rough and cloddy surface resists movement by the wind.

Lister.—The lister has two moldboards and throws the soil in both directions at the same time (Fig. 53). It produces an open

furrow in which corn and similar crops may be planted. Crops resist drought more successfully on listed land than on that plowed in the ordinary way. The place of the lister is in the semiarid and the drier parts of the humid region.

Subsoil Plow.—The subsoil plow, or subsoiler, consists of a shoe that merely lifts the soil and thus loosens it (Fig. 54). The subsoiler is used in the bottom of the furrow made by the regular moldboard plow or in cultivated fields in some sections. It loosens the soil in the bottom of the furrow, but it does not throw any of it out or mix the subsurface with the topsoil (see Tables 20 and 21).

Chilcott and Cole[1] in 1918 reported the results of extensive experiments over a period of years at 12 stations in nine states. From their work, they conclude that subsoiling did not increase crop yields in the area studied. The results of work in Illinois failed to show any beneficial effects on crops. Subsoiling, therefore, cannot be generally recommended.

Deep-tilling Implements.—Several types of deep-tilling implement have been used to some extent. One that was used some years ago was the "deep-tilling machine." It consisted of two disk plows so arranged that the second ran in the furrow of the first, or front, disk. The manufacturers of this plow advised that it did not throw soil out from the bottom of the first furrow and mix it with the surface soil. In practice, however, considerable mixing took place.

The Killefer type of deep-tilling machine (Fig. 55) consists of one or a series of blades or strong knives that are pulled through the soil by means of a heavy tractor. The depth may be adjusted by the operator. It has been used in the West more than elsewhere.

All deep tilling is expensive in that much power is required. Stony land is not well suited to the use of these implements. There is a dearth of data in favor of deep tillage for general farm crops in either arid or humid climates.

Rototiller.—The rototiller (Fig. 56) is in a class somewhat apart from the implements that have been discussed. This implement consists of a series of steel spring hooks that are rotated by

[1] Chilcott, E. C., and John S. Cole, Subsoiling, Deep Tilling, and Soil Dynamiting in the Great Plains, *Jour. Agr. Research*, vol. 14, pp. 481–521, 1918.

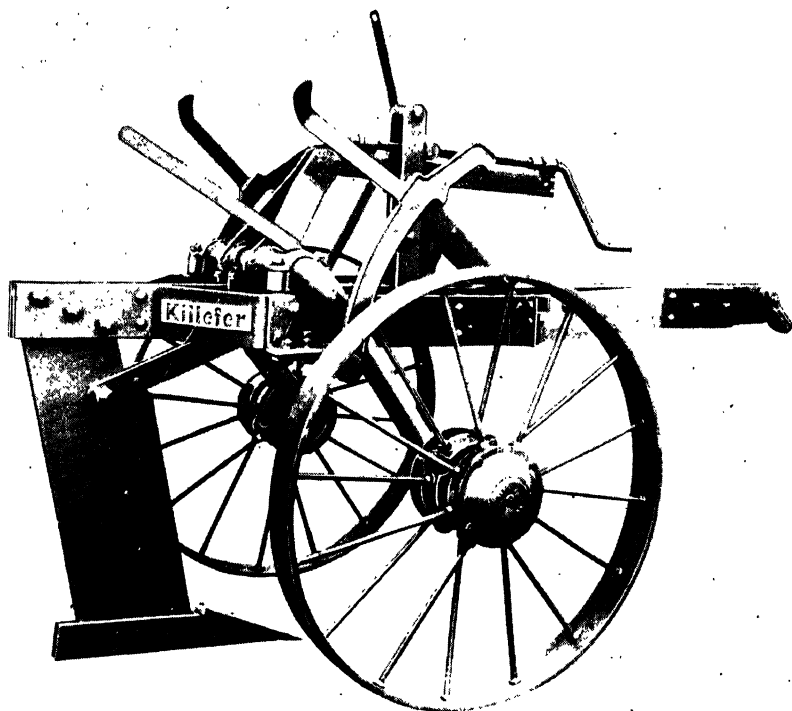



Fig. 55.—The Killefer deep-tilling machine. This implement is used for the purpose of loosening the subsoil. (*Courtesy of John Deere, Moline, Ill.*)

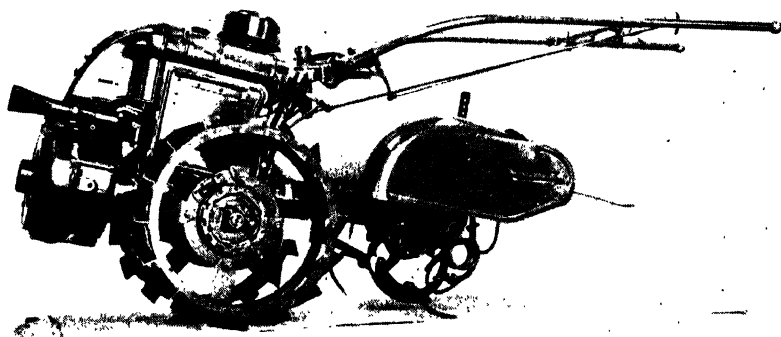



Fig. 56.—The rototiller. This implement performs in one operation the task of the plow and the implements for preparing the seedbed. In other words it loosens and fines the soil in one trip over the land. (*Courtesy of Rototiller, Inc.*)

means of a gasoline engine. The soil is left fine and loose. Since an ideal seedbed is firm underneath with a loose surface, the rototilled soil must settle under the effect of gravity and rainfall or else be rolled. The expense of seedbed preparation with this implement does not appear to be materially lower than that by the conventional methods. Moreover, covering of crop residues is not accomplished so well by this method of tillage, and covering residues is considered essential in humid areas.

Plowing.—In different sections and under different soil, climatic, and cropping conditions, plowing is done at different times of the year.

Time of Plowing.— In the North, plowing is done in three principal seasons, summer, fall, and spring. Some plowing is done during unusually open winters, but this may well be considered fall plowing. In the South, however, much plowing is done in the winter and early spring.

Plowing that is done in preparation for seeding such winter grains as wheat and rye, and oats and barley in the South may be regarded as summer plowing. It is distinguished from fall plowing which is done for the benefit of crops to be seeded the following season.

Experimental work shows that larger yields are produced by plowing as soon as possible after the grains or hay crops have been harvested and removed from the land. Several factors are involved: (1) Early plowing permits natural settling or firming of the furrow slice as a result of rains and gravity. (2) The organisms of the soil have time in which to bring about the decay of the residues from the preceding crop and to change the nutrients in them to a condition of at least partial availability to the fall-sown crop. Moderately early plowing (a month or preferably more before seeding time) produces the best yields of wheat.

Plowing in the fall, called "fall plowing," is particularly desirable on heavy soils especially if they are well supplied with organic matter. Under these conditions, freezing and thawing, and in lesser measure wetting and drying, tend to bring about granulation. This is essential in most of the heavier silt loams, clay loams, and clays. The beneficial effects of freezing and thawing are less pronounced if the organic content of the soil is low.

It has been stated that fall plowing may be done with little regard to the moisture content of the soil, in other words, that in the fall it is safe to plow soils that would be regarded as entirely too wet and in danger of puddling badly if plowed in the spring. If plowing is done so late that freezing occurs almost immediately afterward, plowing such wet soil may be safe. In general, however, attention is called to the danger of injury by destroying the granules of wet, heavy soils, even by plowing in the fall.

Under favorable conditions, fall plowing is desirable because of the attendant improvement in tilth. It may be pointed out, however, that plowing in the fall under certain unfavorable conditions is definitely undesirable. First, flat or level land, a considerable part of which may have water standing on it during part of the winter or early spring, ought not to be plowed in the fall, because freezing and thawing of wet soils may cause puddling. Even though freezing does not occur, the effect of gravity is to bring the wet particles and tiny granules into very close contact with each other. Fall-plowed soil under these conditions is usually very compact in the spring.

Furthermore, sloping land that is subject to washing while the soil is not frozen had better not be plowed in the fall. An exception might be made in the sections where the soil is normally protected by a cover of snow throughout the entire winter. Sandy soils that are subject to much blowing had better be left unplowed until spring. The previous season's crop residues on the surface may materially check soil movement by winds. Strongly granulated, heavy clay loams frequently blow considerably in winter when the soil is frozen. If snow covers these soils most of the winter, little movement of soil takes place.

Plowing in the fall is desirable from the standpoint of distribution of labor, especially if plowing is done with horses or mules. In addition, the period over which plowing may be done is usually longer in fall than in spring. During late springs, it is a distinct advantage to have some of the land fall-plowed.

In a wet spring, fall-plowed land may be surface stirred in the production of a suitable seedbed some days before the land is dry enough for plowing to the usual depth. Seeding may then be done earlier than if the plowing must all be done in the spring. Except under definitely unfavorable conditions, fall plowing,

because of the many attendant advantages, is to be regarded as a desirable feature of good soil management.

Spring plowing is best done as early as the soil is dry enough to be worked properly. It is particularly undesirable to plow silt loam and heavier soils when they come off the moldboard very slick and shiny. Moldboards are purposely curved to pulverize the soil. If the soil is too moist, it is puddled instead of desirably pulverized. Once this puddled, or run-together, condition has been brought about, it may persist over a period of years.

Plowing early in spring is essential in order that desirable natural settling may occur. Late spring-plowed soils seldom attain a desirable, firm condition of the lower part of the furrow slice even if the land is rolled with the cultipacker.

If plowing is deferred until near seeding time, harrowing or cultipacking of the lower part of the furrow slice is essential. Best results are usually obtained if harrowing follows soon after plowing. If the soil is dry and turns over lumpy, going over the land plowed each half day with the cultipacker aids greatly in the production of a fairly good seedbed. This timing should be followed because the clods become much harder as a result of even a few hours of drying sunshine. And any ordinary amount of work fails to produce a satisfactory seedbed from hard clods.

Depth of Plowing.—The depth of plowing deserves attention. Much shallow plowing, 5 inches or less, has been done in times past and is practiced in certain places today. With the advent of the multiple hitch for horses and mules and the tractor, deeper plowing has been done. With the tractor as power, it has been urged that plowing be done to a depth of about 10 inches. Increasing the depth greatly increases the cost of plowing. It

TABLE 20.—AVERAGE YIELDS PER ACRE FOR 12 YEARS FROM PLOWING TO DIFFERENT DEPTHS*

Crop	Ordinary plowing, $7\frac{1}{2}$ in.	Deep plowing, 15 in.	Ordinary plowing subsoiled
Corn, bushels	61.13	59.47	61.33
Oats, bushels	49.00	49.29	49.05
Wheat, bushels	31.50	31.49	31.65
Clover, pounds	5,300	5,060	5,200

* Forty-first Annual Report, *Ohio Agr. Exp. Sta., Bull.* 362, p. 11. 1922.

is well, therefore, to study the effect of various depths of plowing on yields of crops. In Tables 20 and 21 are given the yields produced by plowing to various depths.

TABLE 21.—EFFECT OF DEPTH OF PLOWING AND ADDITIONAL TILLAGE ON CROP YIELDS IN ILLINOIS*
(Bushels to the Acre)

Plowing and other treatment	Corn (9 crops)	Soybeans (7 crops)	Wheat (6 crops)	Sweet-clover seed (6 crops)
Plowed 7 in.	40.2	16.3	13.5	3.68
Subsoiled 14 in.	41.9	16.2	12.9	3.65
Deep-tilled 14 in.	37.4	15.2	10.8	3.18
Dynamited (plowed 7 in.)	40.3	16.4	11.7	4.25

* SMITH, R. S., Experiments with Subsoiling, Deep Tilling, and Subsoil Dynamiting, *Illinois Agr. Exp. Sta., Bull.* 258, p. 163, 1925.

It is seen from the tables that in neither the Ohio nor the Illinois work did plowing deeper than about 7 inches produce increases in crop yields. Other work in Illinois showed inferior yields from plowing to depths of much less than 6 inches. Varying the depth of plowing somewhat from year to year may help in avoiding the formation of plow pan. Even where greater depth is desirable, it is wise to increase it only slightly at any one time, over previous depths.

On the basis of the available data, it appears that, from the standpoint of the cost of plowing and the yields of ordinary feed crops, best results follow plowing to the depth of 6 to 7 inches.

Additional Subsoil Treatment.—Additional treatment of the subsoil by means of the subsoiler (page 139), the different deep-tilling machines, or dynamiting the subsoil has been advocated at various times. Much experimental work has been done in an effort to answer the question: Does it pay?

Dynamiting hard, impervious subsoils was urged some years ago and like much of the deep tilling failed to prove economical. Such work was done in Kansas and in Illinois. Dynamite may shatter a hard, dry subsoil; but, in a moist, plastic, impervious subsoil, it produces what has been termed a *dynamite jug.* The pressure of the explosion compresses a layer of soil about the

opening made by the dynamite. Under these conditions, such treatment actually makes the soil more impervious than normal.

The work reported in Table 21 was done on a silt loam having a compact, impervious clay layer not far below the plow line. Little effect on crop yields resulted from dynamiting. In some years, charges were placed 8 feet 3 inches apart each way; in other years, they were placed 11 feet apart. No real difference in yields was noted, but the cost of dynamite was much greater for the closer spacing. The cost of the dynamite was prohibitive in either case in view of the absence of benefits. Actual harm may be expected in moist heavy subsoils.

Shattering an actual chemical "hardpan" with dynamite for the setting of fruit trees is another matter. Relatively few charges are required if trees are set 40 feet apart both ways; moreover, in true hardpan the effect of shattering should be relatively permanent and of real benefit to the trees.

Effect of Deep-rooting Crops.—Entirely aside from mechanical treatment of subsoils is the effect of deep-rooting plants. As plants are harvested or die, their roots below the plow depth remain undisturbed in the soil. Upon decay, the space occupied stays open except for the remains of the roots. These openings are effective in aiding drainage into the subsoil. Sweet clover, red clover, and alfalfa root deeply, and their roots decay quickly leaving effective openings in the soil. The roots of trees in virgin soils have the same effects. As the soil is plowed and cropped, however, these openings in timber soils became clogged and drainage is retarded.

Under some conditions, the possibility of opening up of the subsoil by means of crop roots should not be overlooked. Much improvement may follow such treatment under favorable conditions.

IMPLEMENTS FOR SEEDBED PREPARATION

Harrows.—In general, harrows are used for the final preparation of the seedbed. The harrows are suitable for the humid area where a seedbed of pulverized soil is desired. In dry farming, however, the harrows, especially the spike-tooth, are undesirable because they produce a seedbed that is so fine as to be subject to severe blowing during dry, windy periods. Several types of harrow are in use.

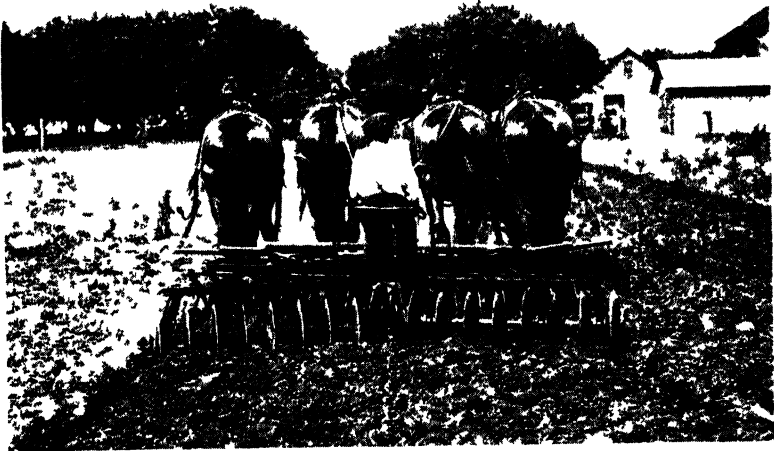



Fig 57 The double-disk harrow The rear disks throw the soil in the opposite direction from the first and double disks the soil in a single operation This implement is made in large units for use with tractor power (*Courtesy of International Harvester Co*)

Fig 58—The spring-tooth harrow Here is shown a two-section horse-drawn spring-tooth harrow Its work is shown further in Fig 61 (*Courtesy of International Harvester Co*)

Disk Harrow.—The disk harrow (Fig. 57) is used for loosening soils before plowing and for loosening fall-plowed land or soil that has been compacted seriously by heavy spring rains. The disk harrow is most useful in soils that are relatively free of stones, especially flat stones. On some sandy or peaty soils, unusually deep disking may be substituted for plowing.

Acme Harrow.—The acme harrow which consists of a series of curved blades is useful in seedbed preparation in stone-free soils.

Spring-tooth Harrow.—The spring-tooth harrow (Fig. 58) is widely used in the northeastern part of the United States and

FIG. 59.—The spike-tooth harrow. This implement is used for fining and smoothing the surface of the soil. (*Courtesy of International Harvester Co.*)

more especially on soils that contain many flat stones, a condition to which the disk harrow is not well adapted. This implement loosens and smooths fall-plowed soils or compacted spring-plowed ones and produces a suitable seedbed for many feed crops. The spring-tooth harrow is well adapted for the killing, or at least control, of various perennial weeds. One objection to this implement is that it drags and distributes stolons or roots of weeds over fields. Beyond question, the dragging implements have helped in the spreading of various perennial weeds. Another objection is that it brings clods and stones to the surface.

Spike-tooth Harrow.—The spike-tooth, peg-tooth, or smoothing harrow (Fig. 59), as it is variously called, is especially useful for

putting the finishing touches on seedbed preparation. It is widely used on the stone-free silt and clay loams of the Midwest where it serves its purpose well. The spike-tooth harrow is probably the most effective implement for fining and smoothing the immediate surface of the plowed soil. It is effective in killing small weeds in a crop such as corn that is not yet large enough for

FIG. 60.—The corrugated roller or cultipacker. This implement compacts not only the immediate surface but the middle of the furrow slice as well. (*Courtesy of John Deere, Moline, Ill.*)

ordinary cultivating. Like the spring-tooth, this harrow spreads the roots of various weeds.

Rollers.—The rollers are used for compacting sandy, peaty, or other loose, recently plowed soils and sometimes for covering meadow-seeding mixtures.

Smooth Roller.—The smooth roller has been in use for many years. It is useful for pressing stones down and out of the way in the spring in meadows and on winter-grain fields where such stones interfere with harvesting operations. On plowed land, the smooth roller tends to compact only the immediate surface

of the soil, for the weight of the roller is evenly distributed over the entire surface of the soil. Consequently, it floats on and packs only the very top of the soil. Such soil is readily puddled by heavy rains. Flat rolling, therefore, may actually facilitate runoff of water and loss of soil by erosion.

Corrugated Roller.—The corrugated roller, or cultipacker (Fig. 60) has been in use for a number of years. Consisting as it does of wedge-shaped disks, its weight is carried on these points. Not only does it crush clods and compress the immediate surface, but the edges of the disks compact the soil well down in the furrow

FIG. 61.- A seedbed in stony soil prepared by means of the spring-tooth harrow. Note the ridges. Under many soil conditions ridges are preferable to a smooth surface.

slice. This compacting is highly desirable because it closes the large spaces between the smaller lumps of soil. Such subsurface packing increases the water-holding capacity of loose soils. This effect of rolling is particularly desirable on light sandy and peaty soils in dry periods. Although the smooth roller may be superior for rolling meadows, the corrugated roller, also, may be used with good effect for this purpose.

Seedbed Preparation.—An ideal seedbed for many crops is firm underneath and has a mellow, weed-free surface. In sandy loams and light loams, the production of a mellow surface is an easy task. Much care and work are required to accomplish the same result on heavy soils. Some points concerning the prepara-

tion of a suitable seedbed were given under Time of Plowing (pages 142 to 144).

A good seedbed is free of weeds. Otherwise, the crop is at a severe disadvantage in that the weeds are well established at the time the crop is seeded. With the weeds under control, however, they and the crop both start from the seed. And since some crop seeds are large and germinate quickly, the crop that is planted in a satisfactory seedbed has some advantage over the competing weeds.

Crops vary somewhat in their seedbed requirements (Figs. 61 and 62). Alfalfa, for example, requires a seedbed that is par-

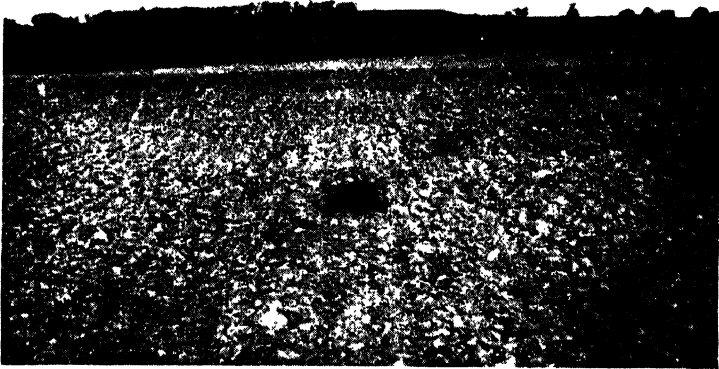



FIG. 62.—Seedbed as left by the hoe drill. This soil contains many rounded stones.

ticularly firm underneath with a mellow surface. Crusting of the surface needs to be guarded against with all legumes because of the manner in which the seedlings push up through the soil. The small grains and corn can emerge through a surface that consists of small clods. In fact, less crusting over takes place on such a surface than on one that approaches a dust mulch. The fine grasses and some of the smaller seeded vegetables require very shallow covering in a fine seedbed.

SEEDING IMPLEMENTS AND SEEDING

Seeding Implements.—A considerable amount of stirring of the surface of the soil is accomplished by the various implements used for seeding crops. Advantage may well be taken of the work

of these implements in the whole scheme of seedbed preparation and weed control.

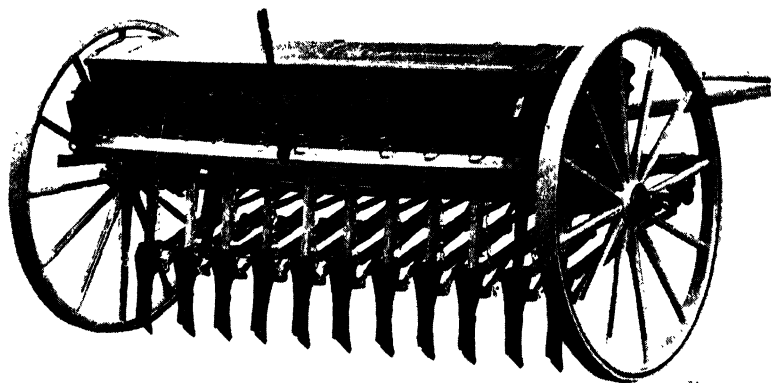



FIG. 63.—The hoe drill. This is a combined grain and fertilizer drill. By means of the chains individual hoes may be lifted for clearing them of trash or stones. When hoes are not in use temporarily they may be tied up with the chains. (*Courtesy of Ontario Drill Co., East Rochester, N. Y.*)

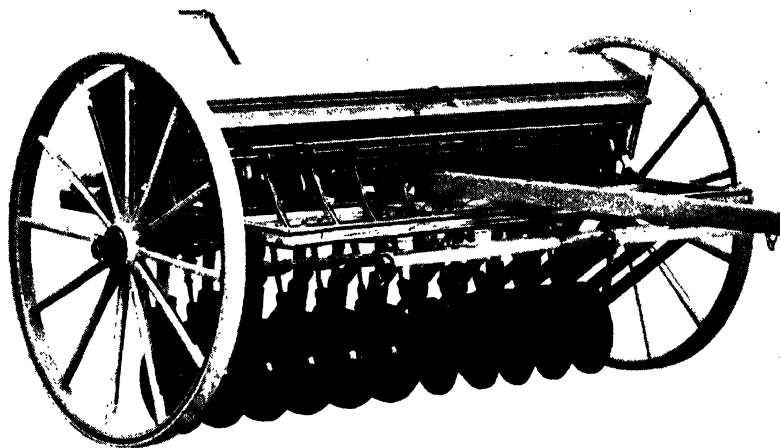



FIG. 64.—The disk drill. The disks make the furrow for receiving the seed and fertilizer much as do the hoes of the hoe drill. (*Courtesy of the Ontario Drill Co.*)

Hoe Drill.—The hoe drill is widely used in the seeding of small grains (Fig. 63). It is especially useful on soils that have numerous large, flat stones. The seed is deposited in the small

furrows made by the individual hoes and is covered by the soil that rolls down into the open furrows. Objections to this drill are that it collects trash and drags and spreads the roots of weeds.

Disk Drill.—The disk drill, which stirs the soil more than does the hoe drill (Fig. 64), is especially popular on stone-free soils and where stalks such as those of corn remain on the surface. Instead of collecting and dragging them along, the disks roll over the stalks and leave them in their original places. The disk drill stirs the soil to nearly the same extent as a light harrowing with the spring-tooth harrow.

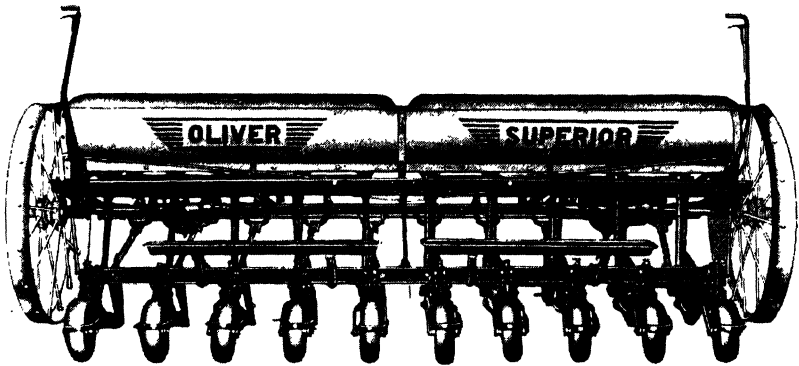



Fig. 65.—The furrow drill. A furrow of good depth and width is opened by means of 16-inch disks and shields which throw the soil in both directions. The seed is then planted in the bottom of these furrows, which afford protection to the seedlings and aid in the control of wind movement of the soil. (*Courtesy of the Oliver Farm Equipment Company.*)

Furrow Drill.—The furrow drill (Fig. 65) is used in the drier areas of the western states. As with the lister, the seed is deposited in the bottom of the furrows. Seeding in this way enables the crop to resist drought more effectively than when seeded at the usual depth for humid areas with the ordinary hoe or disk drill. Moreover, the deep furrows when placed on the contour hold much water following heavy rains. The deeper furrows are effective, also, in catching and holding soil during dry, windy periods.

Potato Planter.—The potato planter acts in much the same way as the furrow drill, the seed being deposited in the bottom of the furrow. The planter stirs the soil to a considerable depth with helpful effects similar to those of other implements.

Other Planters.—Corn, cotton, and bean planters stir the soil only in a minor way. The corn planter, in particular, leaves tracks that should be obliterated by harrowing lest water collect in them on slopes and lead to soil washing. Under such conditions, measures for the control of erosion are needed (see Chap. IX). Plant setters, such as those used for setting cabbage, tomato, and other vegetable plants, stir the soil to about the same minor extent as do the planters for corn, cotton, or beans.

CULTIVATORS AND CULTIVATION, OR INTERTILLAGE

Cultivators.—Cultivators are of a number of types which vary somewhat with the crop, the soil, and the purpose of cultivation.

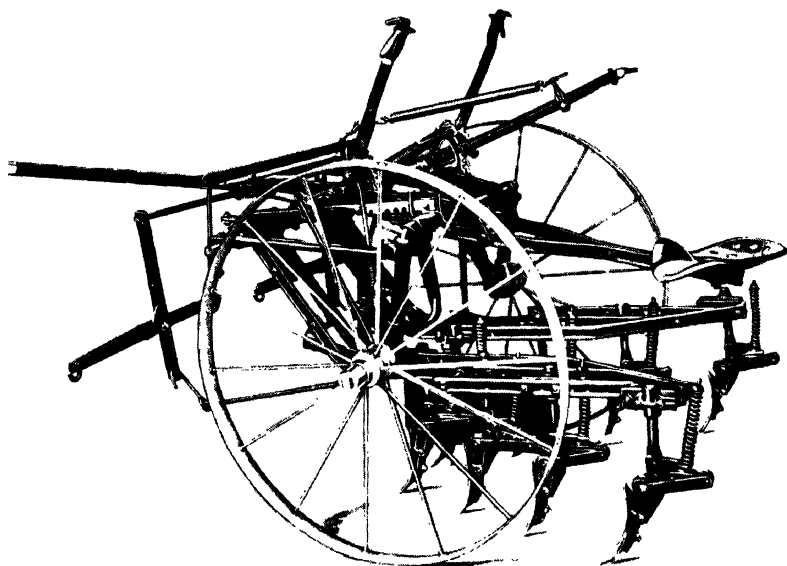



FIG. 66.—The shovel cultivator. This cultivator has four small shovels that work on each side of the row. Corn and other crops may be given relatively shallow cultivation or intertillage with this implement. (*Courtesy of Massey-Harris Co., Racine, Wis.*)

Some widely used cultivators may be mentioned. One-horse and hand cultivators all operate on the same general principles as the larger ones.

Shovel Cultivators.—Shovel cultivators are widely used (Fig. 66). They consist of two, three, or four shovels on a side. The

size of shovel varies with the number used; it is smallest with four and largest with two shovels on a side. The depth of cultivation is often greater when the larger shovels are used and, conversely, may be shallower if the smaller shovels are employed. Fairly deep stirring, however, may be done with the smaller shovels. The dragging of trash and the spreading of weed roots are valid but minor objections to the shovel cultivator.

Disk Cultivators.—The disk cultivator has three or more disks on a side. They are similar to those of the disk harrow and stir

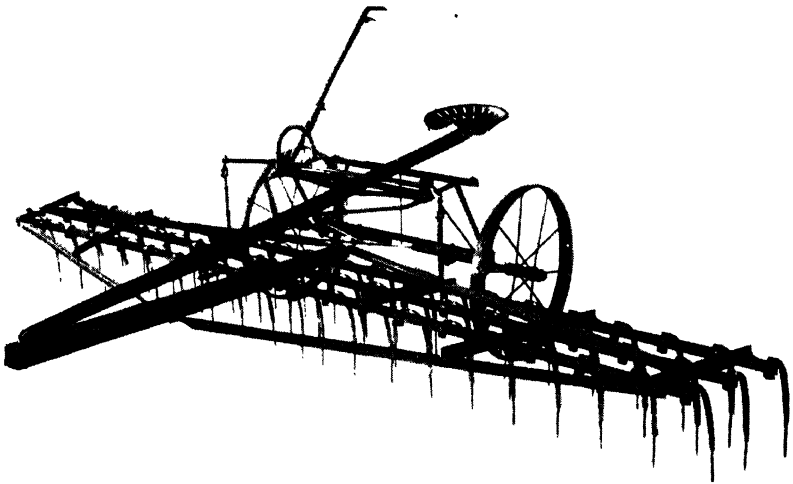



FIG. 67. The weeder. The weeder is a highly useful, light implement for the cultivation of corn and other crops during the early stages of growth. It serves well, also, for covering such small seeds as those of clover, alfalfa, and grasses for hay and pasture. (*Courtesy of Wiard Plow Co., Batavia, N. Y.*)

the soil in the same manner. The disks are capable of rolling over trash without dragging it along. Moreover, the disk cultivator, like the disk drill, does not collect and spread weeds. The disk cultivator, however, is far less widely used than the shovel cultivator, partly because it is not well adapted for stony soils.

Blade Cultivators.—The blade, or surface, cultivator consists of two blades or sweeps on each side. The blades are set to cut barely under the surface. Their purpose is to scrape the weeds off at the surface without materially stirring the soil. The tendency is to carry some soil toward the row, but only a slight ridge is built up. On some cultivators, the shovels may be removed and

blades put in their place. By this shift, the final cultivation may be made with the blades and thus be as shallow as desired.

Weeders.—The weeder (Fig. 67) is a light implement with flexible teeth. It is effective, especially in the control of small weeds, and is easily operated. The weeder may be used on corn until it is 12 or 15 inches tall if soil conditions are such as to permit sufficient stirring with a light implement. It is useful on soybeans, too. The plants being tender in early morning, the crop is stirred with the weeder only during the hotter, drier part of the day when the plants are tougher and more resistant to

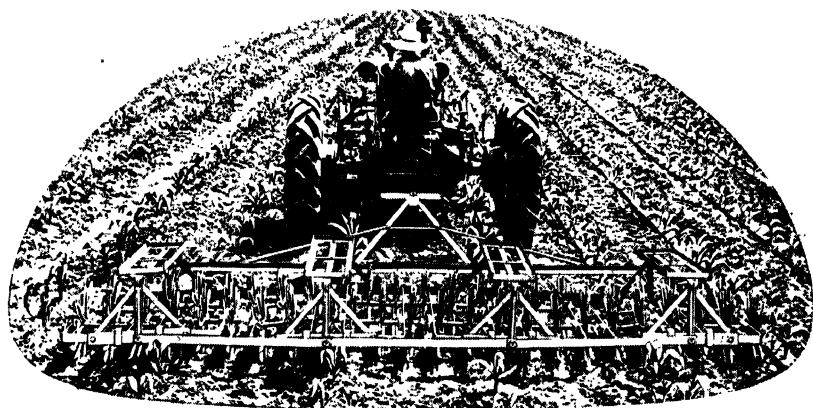



FIG. 68.—The rotary hoe or flexi-hoe. The rotary hoe and the work it does are well illustrated here. At the left, note the complete stirring of the soil around the individual corn plants. (*Courtesy of Blount Plow Works, Evansville, Ind.*)

mechanical injury. The weeder saves much time in the cultivation of small corn. Many farmers use the weeder for covering meadow-seeding mixtures because it gives small seeds the desired shallow covering. The rotary hoe (Fig. 68) is useful for killing weeds in relatively stone-free soils, particularly when both weeds and crop plants are small.

Cultivation, or Intertillage.—Cultivation, or intertillage, consists of stirring the surface soil between the rows of crops by means of various types of implement. These may consist of hand hoes or rakes, one-horse cultivators, or multiple-row, tractor-drawn implements.

Depth of Cultivation.—Three general types of cultivation are practiced. One grades imperceptibly into another, and yet they

may be classified as surface, shallow, and deep. Another type, very deep, might be added to designate such stirring as ridging during the final cultivation of potatoes.

Surface cultivation is a mere scraping of the surface to a depth of 1 inch or less. Even this shallow stirring moves some soil toward the row. Shallow cultivation may be regarded as being to a depth of 1 to 3 inches. Deep cultivation is more than 3 inches in depth.

During the eighties of the past century, a number of state agricultural experiment stations studied the cultivation of corn. The small plow and the large-shovel cultivator, still in use to some extent, had been commonly used up to that time. In this early work, it was found that the roots of the corn plants were being cut off or "pruned" to a very marked degree.

Early in the twentieth century, additional questions with respect to depth and kind of cultivation were studied at the Illinois Agricultural Experiment Station. Scraping the weeds off at the immediate surface was the method of "surface" cultivation practiced on small experimental areas. In addition,

TABLE 22.—EFFECT OF TILLAGE AND CULTIVATION ON CORN YIELDS*

Plot number	Kind of tillage and mode of cultivation	Urbana, average of 8 years		Fairfield, average of 4 years
		Yield of shelled corn, bushels	Yield expressed as per cent of plot 4	
1	Not plowed or cultivated, weeds controlled by scraping with a hoe	36.0	80.4	38.7
2	Plowed, seedbed prepared, weeds killed by scraping with a hoe	48.7	108.7	115.5
3	Plowed, seedbed prepared, weeds allowed to grow	7.0	15.6	34.5
4	Plowed, seedbed prepared, given three shallow cultivations	44.8	100.0	100.0

* Adapted from The Cultivation of Corn, by D. C. Wimer and M. B. Harland, *Illinois Agr. Exp. Sta., Bull.* 259, pp. 180 and 190, 1925.

"shallow" cultivation was compared with allowing the weeds to grow unmolested. The yields are given in Table 22.

Two points stand out in these data: (1) Plowing or other method of loosening the soil is essential for good yields of corn. (2) Corn cannot compete with weeds, the yield of the weed plot being only 7 bushels as compared with 45 bushels on the plot that was given three shallow cultivations. If the latter yield is taken as 100 per cent, the product of the weed plot was 15.6 per cent, or the weed plot produced less than one-sixth as much corn as did the shallow-cultivated one. Scraping increased the yield slightly over three shallow cultivations.

Another experiment at the Illinois Agricultural Experiment Station started in 1916 and running for 6 years gave similar results. These data are given in Table 23.

TABLE 23.—EFFECT OF DIFFERENT METHODS OF SHALLOW CULTIVATION ON CORN YIELDS*

Plot number	Kind of cultivation	Yield, average of 6 years, bushels	Yield expressed as per cent of plot 4
1	Weeds allowed to grow	7.0	13.7
2	Weeds killed by scraping with a hoe	53.3	104.3
3	Cultivated (surface or blade cultivator)	53.0	103.7
4	Cultivated (small shovels)	51.1	100.0

* Adapted from The Cultivation of Corn, by D. C. Wimer and M. B. Harland, *Illinois Agr. Exp. Sta., Bull.* 259, p. 193, 1925.

In this work, the blade, or surface, cultivator was introduced. Curiously enough the yield on the weed plot was identical with that in the earlier work, 7 bushels to the acre. The "scraped" plot gave a yield essentially identical with that produced by the blade-cultivated plot, and both of these plots were 2 bushels higher than the plot cultivated with small shovels.

All this work shows conclusively that corn cannot compete with weeds. They must be controlled by some means that does not injure the corn roots too greatly. And the shallowest cultivation that controls weeds is best for corn. In some years, weeds may get a good start during periods that are too wet for cultivation. When the soil dries out, it will be necessary to cultivate deeply enough to kill the weeds even though the corn roots may

suffer some injury. This root injury is probably less detrimental to the corn than the weeds would be if not controlled.

The effect of cultivation on the production of vegetables is shown in Table 24.

TABLE 24.—EFFECT OF CULTIVATION ON YIELD OF VEGETABLES*
(Average for 6 years)

Vegetable	Hand cultivated, pounds per plot	Scraped with hoe, pounds per plot	Increase made by cultivation, per cent
Beets	60.6	58.1	4.2
Carrots	86.7	84.4	2.7
Onions	77.5	72.0	7.7
Cabbage	119.0	119.4	0.0
Celery	144.5	116.4	24.1
Tomatoes	188.0	185.9	1.1

* THOMPSON, H. C., Experimental Studies of Cultivation of Certain Vegetable Crops, *Cornell Univ. Agr. Exp. Sta., Mem.* 107, 1917.

It will be noted that except for celery there is little difference between the yields produced by scraping with a hoe and by hand cultivation. Cultivation produced nearly one-fourth more celery than did scraping. At the beginning, Prof. Thompson had plots in which the weeds were allowed to grow. The weed plots, however, were discontinued after the first year because vegetables, like corn, failed to compete with the weeds. On a practical basis, shallow cultivation is best for vegetables.

Effects of Cultivation.—Some of the work that has been done on moisture, although perhaps inadequate, suggests that the moisture content of the soil in humid and arid climates is not materially affected by the different methods of cultivation. This being true, the effect of cultivation in both humid and arid climates is the control of weeds. And since most cultivated crops are unable to compete with weeds, cultivation becomes absolutely essential for the production of most of the regularly cultivated crops. Intertillage aids in keeping the topsoil loose so that rain water in humid areas and irrigation water in arid ones may be more readily absorbed.

Questions

1. In view of the labor and expense involved, what are the more important purposes served by tillage operations?

2. Discuss plows and plowing for various soil, climatic, and cropping conditions.

3. Discuss time and depth of plowing with respect to expense and crop yields.

4. Discuss mechanical subsoil treatment in addition to plowing and the effects of deep-rooting crops on subsoils.

5. Under what conditions are the different harrows and rollers effective in completing the work of seedbed preparation?

6. In what way and to what extent do the seeding implements improve the seedbed?

7. Compare the work done by the different types of cultivator.

8. Discuss the results of different depths of cultivation or intertillage.

9. Discuss the results of cultivation of vegetables and of corn.

10. In view of the results of cultivation experiments, what is the principal purpose of cultivation?

CHAPTER VIII

EROSION OF THE SOIL

The movement of soil materials by wind and water is an age-old problem. Before the earth was clothed with vegetation, wind and water shifted the finer soil materials from place to place over the surface of the earth as a phase of the placement of soil

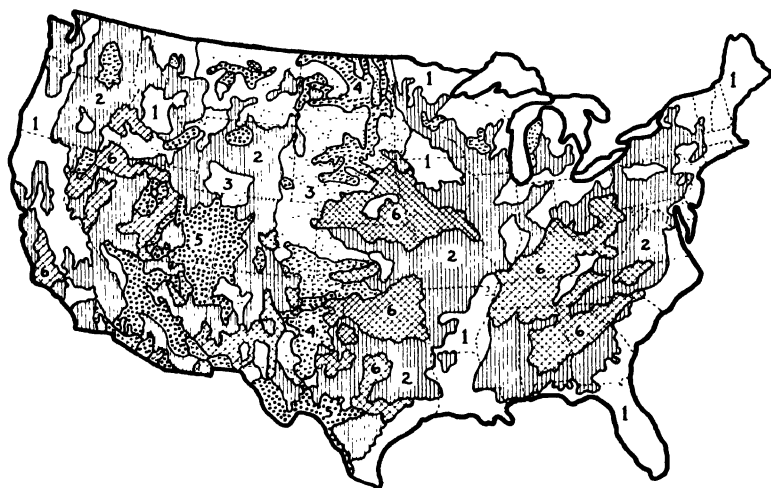



FIG. 69.- Relative erosion in the United States. 1, erosion not serious except locally; 2, moderate sheet and gully erosion, serious locally; 3, slight wind erosion, and moderate sheet and gully erosion; 4, moderate to severe wind erosion, local gullying; 5, moderate to severe erosion, includes mountains, mesas, canyons, and badlands; 6, severe sheet and gully erosion. (*Redrawn from reconnaisance data collected by the U. S. Soil Conservation Service.*)

materials. In this and the succeeding chapter, the erosion that has occurred since man began to till the land receives consideration. This erosion is the direct result of the management of the soil by man in his effort to obtain a living from it. Such erosion is often referred to as *accelerated*, *culturally induced*, *man-made*,

or *man-induced* erosion. Because the only erosion over which control can be exercised by man has been induced by him, the simple term *erosion* is used for it in the succeeding pages. Detrimental soil erosion in the United States had its beginning soon after man began to produce clean-cultivated, soil-exposing crops on sloping lands on which rain fell in heavy showers (Fig. 69).

SOIL ORIGINALLY PROTECTED BY VEGETATION

In the humid parts of this country, most of the land originally was covered with vegetation which consisted of forests and grasses.

FIG. 70.—Forest trees protect the soil. The soil is completely covered by forest litter. The annual crop of leaves and twigs and branches maintains this perfect protection of the soil. (*Courtesy of U. S. Forest Service.*)

Forests.—In all the eastern, southeastern, and northern sections and the humid parts of the West (except at the higher elevations), trees constituted the vegetative protection against erosion. The pioneers found the eastern seaboard a forested wilderness.

Under these conditions, the soil was well insulated against the action of the rain. In summer, the leaves checked the fall of the raindrops, and at other seasons, the twigs and branches of deciduous trees had some of the same effects. The evergreens protected

the soil in this way throughout the year. Moreover, the forest floor was originally covered with twigs, branches, and leaves (Fig. 70). If more water fell than the litter and the soil could absorb, it ran off clear over the surface. Generally, it carried little or no soil and, therefore, caused little or no erosion. Once in the channel of streams, such runoff water did erode both bed and banks. Such erosion was less pronounced then, for the excess water reached the streams at a more leisurely rate than now. The effect of the trees and of the litter on the forest floor was not only to retard but to reduce materially the total runoff to streams.

Prairie Grasses.—In the Midwest and on the Great Plains, the native prairie grasses had much the same protective effect on the soil as did the forest in other sections. The stems and blades of the grasses intercepted the raindrops, and as the leaves and stems fell to the soil they formed a protective cover of organic matter similar in effect to that on the forest floor. Fires destroyed the dry, aboveground parts at times. A new growth, however, soon produced ideal protection again, and little erosion took place as a result of burning the accumulated grass.

The white man plowed down the prairie grasses in order to plant his crops much as he had already cut and burned the forests. He needed food for his family and feed for his livestock. This called for the production not only of vegetables and grains but of forage as well. The original organic covering of the soil when plowed under decayed and disappeared in a few years.

Thus nature's protection of the soil was largely destroyed. Raindrops beat the soil into suspension, and the pores were clogged with fine material. Moreover, the loss of active organic matter from the soil induced a breakdown of the natural granules, caused a reduction in the sizes of the pores, and diminished the rate of absorption of rain water. The result was runoff of muddy water, loss of soil—erosion. Thus, erosion in this country came into play in an early day on exposed, sloping lands under a heavy-shower type of rainfall.

EARLY RECOGNITION OF SOIL EROSION

The damage already done to their lands by erosion was recognized in their day by Washington,[1] Jefferson, and other

[1] HALL, A. R., Early Erosion-control Practices in Virginia, *U.S. Dept. Agr., Misc. Pub.* No. 256, 1938

prominent eighteenth- and early nineteenth-century farmers. And erosion occurred then only a few years after the forests had been cleared and the land brought under the plow. The agricultural papers of that period devoted much space to discussions of ways and means of checking losses of soil by erosion.

In 1769, George Washington experimented with different methods of reducing the loss of soil on his lands at Mount Vernon. Thomas Jefferson in 1817 is credited with the remark that "fields are no sooner cleared than washed," and Patrick Henry with saying " . . . he is the greatest patriot who *stops the most gullies.*" In 1819, Thomas Madison urged farmers to practice soil-saving methods of cultivation. He held that, unless the soils were protected from severe washing, *ownership* of the sloping red lands of the Piedmont was equivalent to no more than a *lease for a few years.* He believed that damage to the soil by washing was so general and so severe that "very little hilly land [in Prince Edward County, Va.] cleared more than 20 or 30 years had any value." Corn and tobacco had been grown so much that they were more or less blamed for erosion. Several prominent men of the time recognized the real causes of what they called "culturally-induced" erosion. In 1801, Thomas Moore wrote: "Thus the land becomes sterile not so much from the vegetable nutriment being extracted from the soil by the growth of plants, as by the soil itself being removed; . . . it [sterility] is [results] more from the manner of cultivation than from the exhausting properties of the crops. . . . "

These fragmentary quotations show that soil erosion was a pressing problem in the Southeast even in Colonial times. Around 1800, the relatively level, rich lands of the Midwest were still to be brought under cultivation. Instead of devising methods of farming these eastern lands and at the same time holding erosion within reasonable limits, the farmers moved westward. An unnamed writer is credited with this view: " . . . The scratching [shallow-plowing] farmer's cares and anxieties are only relieved by his land soon washing away. As that goes down the rivers, he goes over the mountains." In a word, after their land became badly eroded, the farmers went over the Allegheny Mountains to start anew on the rich lands of the Midwest. The surface-washed and gullied fields were left behind for nature to ruin or to protect by means of volunteer vegetation according to

conditions. The effect of these practices is still in evidence in parts of the Southeastern states.

In the long-inhabited parts of the world, such as the Orient and the high plateaus of Peru in South America, the ancient farmers recognized the lack of stability of sloping cultivated lands and employed ingenious means for holding the soil in place (Chap. IX).

KINDS OF EROSION

An effort has been made to classify the various kinds of erosion. The agencies of erosion are water, wind, and waves.

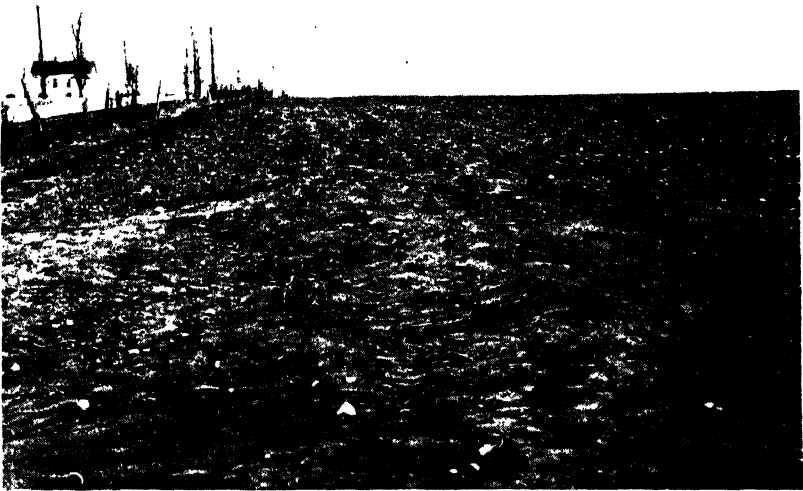



FIG. 71.—Sheet erosion on Ontario loam in New York. The slope is 3 per cent. Much damage has been done to this gently sloping soil.

Water Erosion.—Erosion of the soil by water may be regarded as divided into three fairly natural classes: sheet, rill, and gully erosion.

Sheet Erosion.—Sheet, or surface, erosion may be defined as the more or less uniform removal of soil from the surface of sloping lands (Fig. 71). We shall see later, however, that the removal is seldom uniform from all parts of slopes. Nevertheless, this definition does serve to distinguish sheet, or surface, from rill and gully erosion.

In the early stages of erosion, the loss of the surface soil often goes unnoticed by the farmer. Moreover, because surface soil

is removed from all parts of slopes, the total loss of soil over a period of years is very great indeed. Because of its insidiousness, the wide area covered, and the large amount of valuable topsoil removed, sheet, or surface, erosion does more total damage to cultivated lands than do the other forms of soil erosion by water.

Rill Erosion.—Rill erosion consists of tiny gullies formed by heavy rains on bare soil (Fig. 72). Rill erosion often is severe on land that is being fallowed for wheat, particularly in the

FIG. 72.—Rill washing in New York. This rill washing occurred in June, 1940. The furrows left by tillage implements facilitated this rill washing in the central background with a slope of about 6 per cent. It is steeper in the immediate foreground.

dry-farming sections of the West. Unprotected, sloping land, anywhere, at any season of the year except when frozen, if subjected to heavy-shower rainfall is likely to suffer from rill washing. In addition, rill washing may occur at the time the frost is going out of the soil or during periods of alternate freezing and thawing. Rainfall on thawing soil greatly increases rill and surface erosion.

When rill-washed land is prepared for seeding, the stirring fills the rills. Rill washing in effect then becomes sheet washing. In fact, rill washing is an intermediate stage between sheet washing and gullying.

FIG. 73.—Gullying following severe rill washing. Rill washing down the corn rows has developed into an early stage of severe gullying. The slope in the rows is 14 per cent. (*Courtesy of U. S. Soil Conservation Service, Illinois.*)

FIG. 74.—Gullying on land formerly cultivated. Unless checked very soon these gullies will eat their way far up onto this gently sloping field. Immediate application of gully control measures is essential. (*Courtesy of U. S. Soil Conservation Service, Missouri.*)

Gully Erosion.—Gullies are simply enlarged rills, the difference being primarily one of size. Rills are usually close together; gullies, on the other hand, often occupy natural drainage ways or those produced through the concentration of water by tillage operations. Gullies are relatively narrow gorgelike channels (Figs. 73, 74, and 75).

True sheet erosion results in the loss of surface soil only, whereas the soil lost by gullying is primarily subsurface and subsoil. The surface soil has been largely removed by sheet erosion

Fig. 75.—Gullying in Tennessee. Growing nonprotecting crops on the slopes at the right caused the condition shown here. These gullies average about 5 feet in depth. The pasture on the left, while eroded considerably, can be saved and made to produce fairly good yields of grass and legumes. This mixture can improve the soil and eventually bring erosion under complete control. (*Courtesy of Tennessee Valley Authority.*)

previous to gully formation. Except in places with unusual concentrations of water that result from man's work, gullying normally follows severe sheet erosion.

Though sheet erosion may go unnoted for some time, gullies are so spectacular as to be noticed immediately upon forming. Gullying, because of the relatively narrow belts actually affected, does not cover large areas. If, however, moderately large gullies are formed at relatively frequent intervals, the entire slope is rendered unsuited for the production of many crops. Such intergully areas may be used for pasture or meadow; but, for cultivated or intertilled crops, which should be grown on the

contour, production costs would be entirely too high. Such gullied land, therefore, is usually relegated to use for the production of low-return crops or is reforested or abandoned. If abandoned, nature completes its destruction by further washing or eventually clothes it with protecting vegetation and starts the long process of restoration. Which development takes place depends on both soil and climatic conditions.

Wind Erosion.—In humid areas the movement of soil by wind is confined largely but not entirely to sands, light sandy loams,

FIG. 76.—A severe dust storm. The atmosphere carries much soil material in each cubic mile under these conditions. Soils, crops, and animals, including man, suffer greatly from the effects of dust storms. (*Courtesy of John Deere, Moline, Ill.*)

and peaty soils. Sands are often associated with sea and lake shores, river flood plains, and glacial outwash plains. Conceivably, light residual soils also may be subject to movement by the wind. Sands on sea and lake shores are peculiarly subject to blowing because of the unobstructed and nearly continuous wind. Moreover, such sands are nearly free of organic matter, clay, or any other binding material and, consequently, are subject to easy blowing.

Silt loams and granulated heavy soils, if exposed in winter, are subject to considerable wind movement. Road and other ditches are sometimes filled during periods of excessive drifting.

FIG. 77. -Sand caught by a "snow" fence. The fine loose soil material was blown from the adjacent fields in 1935. Any obstruction may cause the deposition of sand in this way. (*Courtesy of U. S. Soil Conservation Service, South Dakota.*)

FIG. 78.—Sand dunes encroaching on apricot orchard in California (1939). The trees die soon after the dunes move on if secondary roots had been produced in the wind-blown material. (*Courtesy of H. A. Hopper.*)

In semiarid areas, dry, bare, unprotected soils, particularly if fine and loose, blow very easily. The soils of a wide belt extending from north to south across the United States and located between the humid area and the Rocky Mountains are peculiarly subject to wind movement. The most severe blowing occurs after a period of relatively dry years. Conversely, little blowing occurs during the years of rainfall that is heavier than average. A glance at Fig. 69 shows the location of the areas of severe wind erosion. The area marked 4 that centers in the Panhandles of

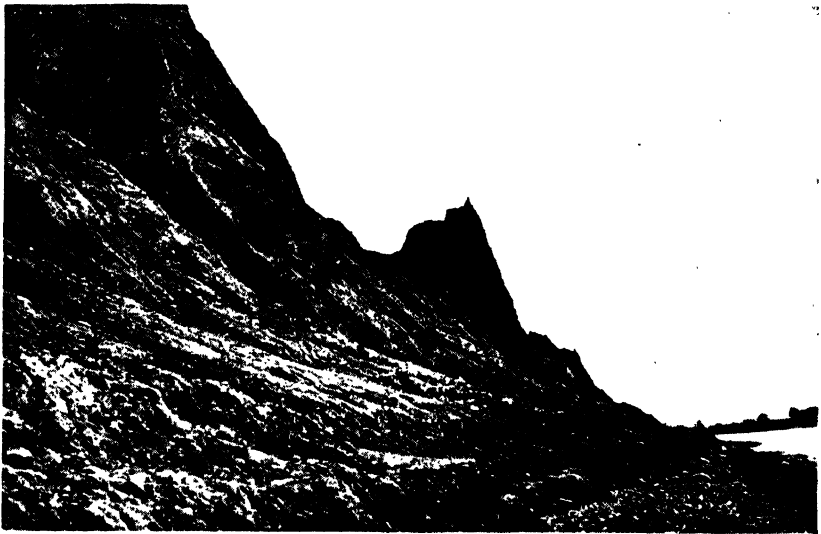



FIG. 79. Erosion on the New York shore line of Lake Ontario. The waves are eating away this shore line of unconsolidated (glacial) material. Stabilization of this material is difficult. Vegetation might prove helpful over a period of years.

Oklahoma and Texas and extends into the three adjacent states of Colorado, Kansas, and New Mexico has experienced severe blowing during the middle thirties of this century (Fig. 76). Smaller areas of severe wind erosion are located in North and South Dakota (Fig. 77), north central Nebraska, Minnesota, California (Fig. 78), Wisconsin, southern New Mexico and Arizona, and northern Nevada. The lightly dotted areas in the Great Plains (3 in Fig. 69), are subject to moderate wind erosion. From the standpoint of agriculture, the blowing of soils on the Great Plains is far more destructive than the blowing of shore sands

already referred to. The latter, however, may be highly destructive to cities, transportation facilities, and to valuable waterfront properties.

Wave Erosion.—Severe wave erosion is confined to unconsolidated or deeply weathered materials on the more exposed points on sea and lake shores (Fig. 79). Some erosion, however, occurs on these shores, generally, and on the banks of the larger rivers as well.

EROSION INFLUENCED BY MANY CONDITIONS

Erosion is influenced by a wide range of conditions varying from place to place, particularly from country to country. Some of the more important conditions in the United States receive attention in the following paragraphs.

Kind of Soil.—Soils vary in the ease with which they erode, or in erodibility. Stated in another way, soils vary in their resistance to erosion. A coarse soil, such as a gravelly loam or a coarse sandy loam, takes up rainfall rapidly; consequently, little water is usually lost as runoff. From this standpoint, these coarse soils may be expected to resist erosion. On the other hand, these soils contain little effective binding material, either clay or organic matter. If water comes onto these soils from higher land or if rain falls much faster than it is taken up by the soil, severe erosion may result. Even so, these coarse soils may be regarded as being of relatively low erodibility under normal conditions.

At the other extreme are the fine-grained soils that were formed in water. Of special interest from this standpoint are the glacial-lake-laid soils of which the Dunkirk, Caneadea, Schoharie, Vergennes, and Hudson in the East are representative. The Dunkirk (Fig. 10) is a heavy soil; yet its topsoil contains but little colloidal clay. The silt in it, however, is so fine that only a small percentage of clay is needed to give the soil clayey characteristics. Unless these heavy soils are high in organic matter and consist of large stable granules as do the black-clay-loam prairie soils of the Midwest, the fine particles are easily beaten into suspension. Once suspended in water, slight movement easily keeps fine silt and clay particles suspended in the current. The colloidal particles remain in suspension in perfectly still water for several months at a time. Very slight movement of

the water in a stream, therefore, is sufficient to keep fine silt particles in suspension for long distances, all of which explains the muddy condition of large streams a long way from their sources.

Another point worthy of consideration is the heavy subsoil of the water-laid formations. Though many of the subsoils are not impervious, drainage through them is slow. These soils, in contrast with the coarse soils mentioned at the beginning of this section, take up water slowly, or have a low infiltration rate. More water from a given rainfall, therefore, is forced to run off over the surface of these clayey soils than from the coarse ones. And since it is the runoff that causes erosion, the heavier soils may be expected to erode more easily than coarse ones.

Another group of soils has a desirable silty surface but is underlaid with a stratum that is impervious, or at least through which water passes very slowly. In some soils, the impervious layer is only 8 or 10 inches below the surface. In others, it may occur anywhere from 10 to 24 inches or more below the surface. The deeper the open surface soil, the greater is its capacity for absorption of water. Once this capacity is completely satisfied, however, additional rain must pass off over the surface and this runoff leads to erosion.

Shallow soils whether underlaid by an impervious clay or by bedrock are more erosive than deeper ones. And soils that possess good internal drainage throughout the profile are relatively resistant to erosion. In part, this greater resistance to erosion results from greater total intake of water by well-drained than by poorly drained soils.

The presence of stones or pieces of shale in the surface soil tends to reduce erosion. The stones protect the finer particles from the beating action of raindrops so that less fine material is brought into suspension and carried away. Moreover, the stones check the movement of water over the surface. By holding it longer in contact with the soil, more water is absorbed and less is lost as runoff and less erosion occurs.

Anything the farmer may do to stabilize the soil granules is helpful, for the water can carry small individual particles much more readily than granules. Conversely, anything that tends to break down the granules or to deflocculate the soil should be carefully avoided. The granules may consist of hundreds or even

millions of colloidal particles. The great importance of stable soil granules in the control of erosion is at once evident.

Slope of Land.—Both steepness and length of slopes exert their own specific effects on erosion of the soil.

Steepness of Slope.—Steepness of slopes may be expressed in degrees or in percentage, but percentage has been adopted in this country as the method of describing slopes. By percentage of slope is meant the vertical drop in feet per 100 feet of horizontal distance. A drop of 10 feet vertical in 100 feet of horizontal distance, according to this method of expression, is a slope of 10 per cent.[1]

Other things being equal, the percentage of slope essentially determines the rate of flow, or velocity of water, over a surface. The velocity of water determines its power of eroding, or tearing, particles loose from the body of the soil and of transporting them. This is true both for weight of the individual particles and for the total quantity of soil materials that may be transported by streams (see pages 16 and 17).

Soil and water losses were compared from slopes of 8.7 and 18.3 per cent from Lordstown stony silt loam and Bath flaggy silt loam respectively at the U.S. Soil Conservation Experiment Station near Ithaca, N.Y., over a period of 3 years, 1936, 1937, and 1938. The two soils are similar, the Bath on the steeper slope being deeper than the Lordstown on the gentler slope. The comparisons cover the period from May through October each year. The 8.7 per cent slope lost 3,500 pounds of soil an acre a year, and 6,500 pounds were lost from the 18.3 per cent slope. And these losses are in line with what would be expected.

The work of gravity is closely associated with that of streams. Gravity acts only in the vertical, or perpendicular, plane. On

[1] Percentage of slope may be determined very easily by means of a level of the Abney type, by means of a level mounted on a tripod, or by means of a carpenter's level. The materials needed for the latter method are a 1-by 3-inch straightedge 100 inches in length, a light carpenter's or other fixed level, and a yardstick. The level may be fastened to one side at one end of the straightedge. The other end of the straightedge is rested on a smooth spot of the sloping soil. The straightedge is held in the true horizontal plane as shown by the bubble in the level. Then, by means of the yardstick, one measures in inches the distance from the surface of the soil to the lower side of the straightedge. This distance, being the inches of drop in 100 inches horizontal, is read directly as the percentage of slope.

very gentle slopes such as those of 2 or 3 per cent, the slope is at almost right angles to the pull of gravity which, therefore, is relatively ineffective. In contrast, gravity is very effective on an extreme slope of 50 per cent. Steepness of slope, therefore, because of its effect on the velocity of flowing water and on its relation to the effects of gravity, exerts a very great influence on soil erosion.

Length of Slope.—Length of slope determines the effective size of the drainage area. The lower part of short slopes is not subject to large quantities of water coming down over it. In contrast, a long slope contributes its excess water, which runs down over the lower part. The runoff from heavy rains is sufficient to cause severe damage to exposed soils on the lower section of long slopes.

Attention is called to the first three figures in the final column in Table 28 (page 195) by Musgrave and Norton. Three lengths of slope were compared. The shorter slope (157.5 feet) loses a higher percentage of water but considerably less soil than the longer slope (630 feet). Because the longest slope is four times the length of the shortest one, it receives four times as much rain. More total water, therefore, is lost and more soil is carried per cubic foot of water than from the shorter slopes.

Similar results were obtained by Lamb and his coworkers in southern New York. The lengths, in fact, strip widths, studied were 36.3, 72.6, and 145.2 feet; and the soil losses were, respectively, 10,989, 7,008, and 11,976 pounds to the acre as an average for 4 years. The percentage of slope was 17 to 18.3.

Vegetative Protection.—Some attention was given at the opening of this chapter to the protection afforded to soils by native vegetation in the form either of trees (Fig. 70) or of grasses. The crops grown have similar effects, varying in degree with the crop. Some crops afford more protection than others. The protection varies in a measure with the density (or completeness) of the cover and with the type, the spread, the persistence, and the tenacity (holding power) of the roots. Biennial or perennial crops are usually far superior to the annual ones in the protection they afford the soil. Grasses and small grains generally give much better protection than do clean-tilled crops.

In Table 27 (page 184) is a comparison of soil and water losses as influenced by vegetative cover and absence of cover. The

fertilized corn lost nearly 28 times as much soil as did the rotation of corn, oats and barley, and clover, while the fertilized meadow lost 1/200 as much as did the land in corn. And the fallow lost more than 3 times as much soil as the corn land.

Rainfall.—Erosion is influenced by the total amount, by the seasonal distribution, and by the intensity of rainfall. If other conditions are identical, it is obvious that a high total rainfall may be expected to cause more soil erosion than a low rainfall (see Fig. 4). If much water comes as snow on frozen soil, it is clear that it causes no erosion there at that time. Erosion, however, may result on bare land from the snow's passing off rapidly as water over partly thawed soil. The same quantity of water as rain, especially if moderately heavy, usually causes more erosion than does water from snow. Thawing snow on unfrozen soil, on the other hand, is largely, if not wholly, absorbed by the soil and thus causes no damage.

Rain or unprotected soil causes more erosion than on soil protected to varying degrees by growing crops. Moreover, during a part of the year the soil under clean-cultivated crops is loose as a result of tillage and, though absorptive, is also easily subject to washing.

The intensity of rainfall exerts much influence on erosion. From the standpoint of soil erosion, sections that receive the rainfall as gentle showers are indeed fortunate. As long as the soil can absorb rain as fast as it falls, no runoff and, consequently, no erosion occur. In many sections of the United States, rain falls much more rapidly than ordinary soils can absorb it. The excess must run off over the surface; and, in the case of bare soils, the water usually carries much soil away with it. Intensities of 1 inch of rain in 10 minutes are not uncommon in many areas, and even higher intensities have been experienced in many sections regarded as having a normal type of rainfall. In southern New York, an automatic gauge recorded 1.3 inches in 7 minutes in 1938. In 1939, 3 inches fell in 45 minutes, and nearly 8 inches in 24 hours at Ithaca, N.Y., in 1935. Such intensities are not uncommon. One inch in 10 minutes often causes severe erosion on bare soils. Once the soil is saturated, additional water must run off to a large extent. It is the runoff from heavy rains that causes such havoc as has been witnessed in various sections of

the country in recent years. It should be borne in mind, however, that the heaviest rains fortunately do not come frequently in most parts of the United States.

Climate.—Little erosion occurs in areas where the soil is frozen most of the year. At the other extreme, soils in the tropics that are never frozen but are protected by heavy natural vegetation may not suffer serious damage. If exposed, however, under the usual tropical intensity of rainfall, serious erosion may occur.

Contrast the northern with the southern part of the United States. In the one, the soil is frozen during a period of 4 or 5 months, whereas on the coast of the Gulf of Mexico freezing seldom and in places never occurs. Erosion does not occur while the soil is completely frozen, but it does take place while the soil is thawing in the spring, particularly, if thawing is accompanied by rain.

In the extreme south where there is little frost in the ground, the soil is exposed to erosion throughout most of the year. And during the cool period of little growth of crops, erosion may be serious when rainfall is heavy. In the broad intermediate zone where alternate freezing and thawing occur commonly, winter erosion may be very pronounced. In the Midwest during open winters with considerable rain, severe washing takes places on cornfields and other unprotected land. Even in New York, exposed sloping land that produced corn, potatoes, beans, or vegetables in the previous year suffers severe losses of soil during thawing in the spring.

The Farmer Himself.—Many of the early settlers in this country came from parts of Europe, notably Great Britain, Scandinavia, and the northwestern part of the Continent, that normally have rains of low intensity. Not being accustomed to intense rainfall, these farmers were not familiar with severe sheet washing and gullying. Moreover, in parts of the area from which these farmers came, the production of forage, or hay and pasture, was of first importance. Under these conditions, it is little wonder that these men were unfamiliar with measures for avoiding erosion. However, some of our best means of control appear to have been brought to this country by men from Switzerland and near-by mountainous areas that receive rains of high intensity.

EXTENT OF DAMAGE TO THE SOIL BY EROSION

The extent of damage in different sections varies greatly and more or less in accord with the different influences that affect the degree of erosion in general. A reconnaissance survey of erosion conditions in this country was made in the fall of 1934 by the U.S. Soil Conservation Service.[1] The findings are given on the pages that follow.

Erosion by Water.—As described in Chap. 1, the formation of soil is a slow geological process. Once the soil has been removed from the underlying rock, a long time will be required to reclothe that rock with soil. Consequently, an area from which all the soil has been eroded ceases to be of much agricultural value. Agriculture depends on the topsoil as its capital; hence the necessity of maintaining it unimpaired.

It is reported[2] that a single heavy rain in July, 1934, washed away more than 1 inch of topsoil from many fields in the Driftless Area of southwestern Wisconsin. It is stated further that "this loss of soil capital was far in excess of the value of the crops produced from these fields in that year."

According to Fuller, nearly one-third of the United States had little or no erosion. Nearly half of the country had suffered from sheet erosion, and such erosion was severe on one-third of the entire land area of the United States. Gullying had affected nearly one-half of the area of this country to some extent. Although the figures present a serious picture, some of this land may be reclaimed if the work is begun without delay.

Loss of Fine Soil Material.—Many soils are deficient in the finer soil particles, notably colloidal clay and the finer silt particles. The function of these materials which has already received attention, is to supply plants with nutrients and to hold water. For this reason, any considerable loss of fine material over a few years causes failure to hold water and a reduction in crop yields.

From what has been said about the action of raindrops on the soil, it is clear that the finer particles are lost to a greater extent than are the coarser ones. This is obvious, for many of the

[1] FULLER, GLENN L., Reconnaissance Erosion Survey Data, *U.S. Dept. Agr., Soil Conservation Service*, SCS-MP-2 (revised July, 1935).

[2] The University and the Erosion Problem (Science Inquiry), *Univ. Wisconsin Bull.*, Ser. 2097; *Gen. Ser.* 1881.

lighter showers remove fine particles but are unable to carry away the larger particles. Moreover, the slopes of most fields lack uniformity. Steep places have slopes below them that are less steep. On these gentler slopes, the coarser materials washed from above are deposited because the water is not moving rapidly enough to transport them. Once in suspension, however, the colloidal material remains so indefinitely, and some of it is carried to the sea except as water is impounded along the way. In addition, the ordinary movement of flowing water is sufficient to keep the finer silt in suspension for long distances. Once churned into suspension by raindrops, this finer material is carried off the fields and the farms whence it came. And it is forever lost from those fields and farms.

With the heavier soils such as silt loams and clay loams, loss of fine material is far less serious than it is from the coarser soils. Gravelly loams, sandy loams, and stony or gravelly silt loams contain so little fine material that if this is lost in any considerable quantity the water-holding power and the productivity of such soils are soon reduced. And this constitutes one good reason for avoiding sheet erosion in so far as practicable.

Productive Soils Covered by Debris.—The landowner or farmer in the valleys sometimes thinks that he is not concerned with soil erosion. His land is nearly level and not subject to washing. He is right in so far as direct loss of soil by erosion is concerned. Much highly productive and high-priced vegetable land lies in the valleys; but heavy rains on the adjacent uplands often carry down immense quantities of stones, gravel, and coarse sand which are spread over the adjacent valley land. A cover of 1 foot or more of such material greatly reduces the value of productive valley soils (Fig. 80).

Isolated instances may be cited where such medium-grained material as the deep loess of the Mississippi and Missouri valleys has been carried down and has covered heavy clay soils or has filled swamps in the bottom land. Such deposition is beneficial to the valley land even though many acres of adjacent upland were badly washed in order to supply the material. In general, however, mankind is the loser from such beneficial effects on bottom lands.

The statement is sometimes made that erosion should be credited with the formation of the highly productive valley lands.

Let us examine the record. When were these valley lands formed? Before or after the beginning of man-induced erosion? In the main, for this country, the answer is *Before*. In the northern half of this country, most of the higher valley land (benches and terraces, or second bottom) was formed from the products of glacial and geological erosion in association with the closing phases of the latest glacial period. These higher valley soils were formed many years before Columbus sighted land in the Western Hemisphere and consequently long before culturally

FIG. 80. Stones deposited by flood waters on productive soil in New York. The value of this valley soil has been greatly reduced by this covering of stones.

induced erosion began. Therefore, no connection exists between the formation of the productive higher valley lands and the kind of erosion with which man now has to deal. Deposition of soil material which occurs at each overflow is, to be sure, building up flood plains. If the deposits consist of weathered surface soil, they have value. Much deposition, however, consists of coarse material of little value.

Silting of Reservoirs.- The silting of reservoirs occurs in the same way as the building up of swamplands with stream-borne sediments. Increasing the velocity of a stream increases the weight and quantity of particles it can carry. In contrast,

reducing velocity reduces carrying power. Stream water, therefore, impounded behind a reservoir dam is completely deprived of its carrying power in the ordinary sense. Colloidal material is, of course, known to remain suspended indefinitely in some reservoir waters. Silt and coarse materials, and more especially the coarser ones, are deposited when the velocity of the water is reduced. Thus land is built up as deltas in the upper part of reservoirs.

Reservoirs in forested areas, or whose tributary streams flow from them, are relatively long-lived because such streams are

Fig. 81.—Schoolfield Dam in Virginia. This reservoir has been nearly filled with sediment. It has, therefore, almost no storage capacity now. The wooded area beyond the middle of the dam is on land built up by sedimentation in the reservoir. (*Courtesy of U. S. Soil Conservation Service.*)

comparatively free of sediment. Reservoirs located in agricultural areas are fed by streams that flow through farm lands having a large acreage of intertilled crops. Such streams are well laden with sediment after heavy rains. Some of this burden is deposited along the course of the streams, but much of it is carried into the reservoir (Fig. 81).

Water-power installations in the wooded Adirondack Mountains have functioned over a period of 100 to 150 years and are still in use. In contrast, reservoirs in the agricultural sections of central New York have been filled with sediment to their very crests, and many dams have been washed away. Almost none of these earlier installations in agricultural areas are functioning

today. Most of them were in use not more than 50 or 60 years. This difference is due to the erosion on cultivated fields as compared with almost no erosion and, therefore, no contribution of sediment from forested areas.

Eakin[1] reported on the rate of silting of reservoirs throughout the country. A few of these reservoirs have an indicated life of more than 200 years. Out of 35 reservoirs studied, 19 will be completely filled at the rate of sedimentation reported in less than 100 years. Of these 19, 12 have an indicated life of 50 years or less. The reservoir formed by the great dam built across the Mississippi River between Keokuk, Iowa, and Hamilton, Ill., early in this century will, according to Eakin's report, be filled in 50 years from the time it was built. Even after this reservoir is filled with soil, the dam will still function for diverting the water to the electric generators. At low stage, however, the production of power will be strictly limited to the flow of the river at that time, since there will be no storage water to draw upon. Two reservoirs at Austin, Tex., according to Eakin's report, will be filled in 14 years, and the Boysen, in Wyoming, in 16 years. A life of less than 100 years makes an expensive reservoir, for the period over which to spread the cost is short.

TABLE 25.—RELATION OF CROPPING SYSTEM TO SOIL AND WATER LOSSES IN MISSOURI*
(14 Years' Results, 1918–1931)

Cultural and cropping systems	Average yearly loss		Number of years to erode 7 inches of soil
	Rainfall, per cent	Soil, tons	
Fallow, plowed 8 in.	30.3	41.1	24
Continuous corn	29.4	19.7	50
Continuous wheat	23.3	10.1	100
Corn, wheat, clover	13.8	2.8	368
Continuous bluegrass	12.0	0.3	3,043

* MILLER, M. F., and H. H. KRUSEKOPF, The Influence of Systems of Cropping and Methods of Culture on Surface Runoff and Soil Erosion, *Missouri Agr. Exp. Sta., Res. Bul.* 177, p. 22, 1932.

[1] EAKIN, HENRY M., Silting of Reservoirs, *U.S. Dept. Agr., Tech. Bul.* 524, 1936.

Measurement of Soil and Water Losses.—Much general work had been done on the control of erosion previous to 1917, but in that year Miller and his associates at the Missouri Experiment Station began definite measurements of the actual losses of soil and water under a variety of cropping conditions. The data covering some of their work are given in Table 25.

The losses of soil and water are heavy both on the fallow and the corn land, especially if compared with those from the land in rotation or bluegrass.

The losses of plant nutrients in the eroded material have been determined by Miller and Krusekopf, their data being given in Table 26.

TABLE 26.—AVERAGE POUNDS OF PLANT NUTRIENTS IN ERODED MATERIAL REMOVED PER ACRE ANNUALLY DURING 2 YEARS, MAY 1, 1926 - MAY 1, 1928*

Treatment	Nitrogen	Phosphorus	Potassium	Magnesium	Calcium	Sulphur
Plowed 4 in. (fallowed).....	118.13	37.75	1,245.55	171.94	458.51	46.72
Plowed 8 in. (fallowed).....	100.16	36.17	1,202.07	179.13	425.31	42.76
Continuous bluegrass.......	0.60	0.16	2.67	0.22	1.07	
Continuous wheat..........	32.39	9.42	264.00	42.67	106.23	8.55
Rotation: corn, wheat, clover	26.36	6.20	213.86	29.18	86.08	5.97
Continuous corn...........	65.90	18.00	605.30	87.29	220.84	16.66

* MILLER, M. F., and H. H. KRUSEKOPF, The Influence of Systems of Cropping and Methods of Culture on Surface Runoff and Soil Erosion, *Missouri Agr. Exp. Sta., Res. Bull.* 177, p. 24, 1932.

Attention is called to the heavy losses of nutrients from the fallow and continuous corn plots particularly, as compared with the bluegrass and the rotation plots. The losses of nutrients for the rotation are from the corn and wheat years and on the average are one-half greater than shown in Table 26, for the loss of soil from clover was only about 1.26 tons an acre a year.

The average losses of soil and water during 4 years from a 20 per cent slope in southern New York are given in Table 27.

From these figures, one sees the very high loss of soil from fallow land. At the rate shown, the surface soil will be lost completely in 90 years. Continuous corn will require 286 years and the rotation, 4,000 years. Since they cover only 4 years one cannot draw definite conclusions from these data.

TABLE 27.—LOSSES OF SOIL AND WATER, BATH FLAGGY SILT LOAM, U.S. SOIL CONSERVATION EXPERIMENT STATION, ARNOT, NEAR ITHACA, N.Y.*
(Average Slope 20 Per Cent. Average of 4 Years, 1935–1938)

Crop	Rainfall,† inches	Losses	
		Water, per cent	Soil, pounds per acre
Corn (fertilized)	23.9	8.3	7,009
Fallow	23.9	17.0	22,231
Meadow (fertilized)	23.9	0.7	35
Idle (weeds, some clover)	23.9	2.5	884
Rotation: corn, oats and barley, clover	23.9	3.1	509

* *U.S. Soil Conservation Exp. Sta.* (near Ithaca, N.Y.), R-39, p. 5, 1939.
† May-October.

Erosion by Wind.—Wind erosion like sheet erosion has escaped attention partly because of the uniform removal of surface material. Extensive production of wheat on the Great Plains since 1915 destroyed the natural protection of prairie grasses and exposed the soil to erosion by wind and water on a large area.

Udden,[1] former state geologist of Texas, has shown the wind to be of great importance in the movement of soils. He estimated that 850 million tons of dust a year are carried an average distance of 1,440 miles over the Mississippi Valley. In comparison, the Mississippi River itself is credited with transporting 400 million tons of soil a year to the Gulf of Mexico.

Large quantities of soil were carried to the eastern seaboard by the dust storms of May, 1934. Hand of the U.S. Weather Bureau estimated that the air over 1 square mile in the vicinity of Washington, D.C., contained 101 tons of soil. He believed this soil to have been derived mostly from the northern part of the Great Plains. Similar dust storms have occurred both before and since 1934. The loss of surface soil in such storms is indeed very great.

Blackwelder[2] estimated that the wind has removed 14 feet of surface material in the Danby dry-lake area in California. The

[1] UDDEN, J. A., The University and the Erosion Problem, *Univ. Wisconsin Bull., Ser.* 2097; *Gen. Ser.* 1881.
[2] *Op. cit.*, p. 11.

deserts of the world supply additional evidence of the capacity of the wind for moving soil materials.

The area affected by wind erosion in this country is much smaller than that injured by water erosion. According to Fuller, one-sixth of this country has been affected by wind erosion. One-eighth of the whole country has suffered moderate injury, and one twenty-fifth has been badly eroded by the wind. Though one twenty-fifth does not seem to be a large fraction, the area that has been most severely damaged by wind erosion is about 9

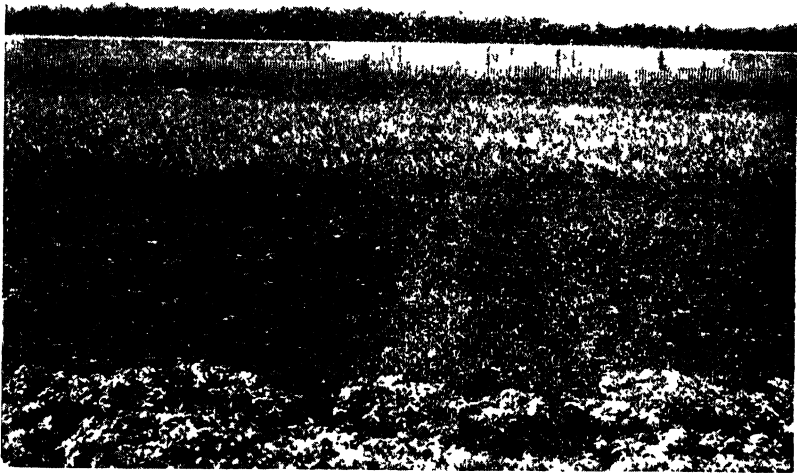



FIG. 82 Injury to crops by blowing peat.

million acres in extent. Fairly severe wind erosion has taken place on nearly 80 million acres. These areas are of sufficient proportions to warrant serious consideration of means for the control of further wind erosion on them.

Injury to Crops by Blowing Sand.—On sands and sandy loams, the wind hurls sharp sand grains against the tender stems of rapidly growing plants which are highly susceptible to this abrasive action of the sand grains. Many plants are killed, and reseeding is necessary in order to produce a crop. Because this entails expense, the farmer suffers considerable loss from such blowing of sand.

Injury to Crops by Blowing Peat.—In a similar manner, the wind in dry periods in spring may blow bits of wood or hard granules of peat against the leaves or tender stems of crop plants, which are mainly vegetables, in the eastern United States. Onions, lettuce, and other sensitive crops are often killed, or "blown out" completely (Fig. 82). This destruction necessitates the seeding of a crop that can mature during the remainder of the available growing period. Much loss results from such injury to crops.

Erosion by Waves.—Waves through their almost incessant action carry away valuable land on ocean, lake, and river shores. Great financial loss follows the destruction of shore lines that are occupied by cities and transportation or recreation facilities. It has been estimated that New Jersey alone suffered a loss of 2,200 acres from 1840 to 1920. Because of its proximity to the New York metropolitan area, the recreational value of this shoreland is great. It is said to be assessed for a sum larger than the total of all the farm land in New Jersey. In Racine County, Wis.,[1] parts of the lakeshore have been cutting back at the rate of 3 to 10 feet a year. The island of Helgoland in the North Sea has been decreased in circumference by wave erosion from 120 miles in the eighth century to 3 miles at the present time. Protective structures may have saved it from extinction. Sharp's Island in Chesapeake Bay which had an area of 438 acres in 1848 had only 53 acres in 1903. It is estimated that it will be completely eaten away by 1950.

The wearing away of farm land by wave erosion is a difficult problem for the individual farmer. Conceivably, government agencies might attack the problem, although it must be admitted that the cost of protection in many places might exceed the value of the land for agricultural purposes.

Questions

1. Discuss the effectiveness of the vegetation found by the white man in America in protecting the soil against erosion.

2. When was the seriousness of erosion in the Southeast recognized? How long had the land been under cultivation?

3. Who were prominently identified with early erosion-control work in the United States?

[1] Udden, *op. cit.*

4. Name the different kinds or phases of erosion, and indicate the relative injuriousness of each.

5. Discuss the more important conditions that influence soil erosion.

6. Indicate the extent of damage to soils in the United States from erosion by water, wind, and waves.

7. What is the relative significance of the loss of sand and gravel as compared with the loss of fine silt and clay from cultivated soils?

8. Of what consequence is the covering of productive soils with coarse material by streams or with wind-blown sand?

9. What is the relative rate of silting of reservoirs?

10. Discuss the value of measurements of losses of soil and water as begun by Dean Miller and his associates.

11. State the ways in which the blowing of sand and peat injures crops.

CHAPTER IX

THE CONTROL OF SOIL EROSION

A century and a half ago, Washington and Jefferson and other progressive students of agriculture not only recognized the menace of soil erosion but did much to reduce losses from it on their lands. Although it can hardly be said that their work led to the development of actual systems for the control of erosion, yet it may well be that their work did serve as the basis for the long-term development of the methods now in use. Interesting as a record would be of what is known of the developments in this country, space does not admit of further statement here of the earlier methods employed.

RECENT EROSION-CONTROL DEVELOPMENTS IN THIS COUNTRY

In this country, not only have experiment-station workers recognized the problem of soil erosion, but they have disseminated information on its control through various publications. Among the early ones that have come to the writer's attention are Practical Experiments in Reclaiming "Galled" or Washed Land by Paul F. Kefauver of the Tennessee Experiment Station, *Bulletin* 4, in 1890, and Farm Drainage by C. L. Newman of the Arkansas Agricultural Experiment Station, *Bulletin* 32, in 1894. The late J. G. Mosier of the Illinois Experiment Station in 1907 established in the southern part of Illinois a field for the study of various measures for controlling erosion. The results of these experiments were published 10 years later in bulletin form.[1] During the next few years much work was started and many publications appeared, especially in the Southeastern states. In addition a number of bulletins were published by the U.S. Department of Agriculture. The classical experiments by Dean Miller and his associates of the University of Missouri on the losses of water by runoff and of soil by erosion were begun in 1917. The results of the first 14 years were published in 1932. Following the general pattern of the Missouri experimental

[1] MOSIER, J. G., and A. F. GUSTAFSON, Washing of Soils and Methods of Prevention, *Illinois Agr. Exp. Sta.*, *Bull.* 207, 1918.

layout, the Bureau of Chemistry and Soils of the U.S. Department of Agriculture in 1928 established a number of experiments for the detailed study of losses of water and soil from a wide range of soil, climatic, and cropping conditions throughout the country. Invaluable data from these experiments are now being published from time to time.

THE ESTABLISHMENT OF THE SOIL CONSERVATION SERVICE

In 1933, the federal *Soil Erosion Service* was established in the U.S. Department of the Interior under the direction of H. H. Bennett. Later, it was transferred to the U.S. Department of Agriculture and broadened into the *U.S. Soil Conservation Service*. A further broadening along the lines of soil utilization was effected late in 1938.

The Soil Conservation Service established a large number of projects throughout the United States for the purpose of demonstrating practical ways and means of controlling soil erosion on the lands of cooperating farmers. This work has shown that the necessary food, forage, and fiber can be produced and that the loss of soil by erosion can be greatly reduced at the same time.

THE CONTROL OF WATER EROSION

From the erosion conditions in this country and the rather heavy losses of both soil and water that were described in the preceding chapter, the need for a determined effort to accomplish a goodly measure of control of soil erosion by wind and water is obvious. An immediate, persistent attack on this problem on a wide front is essential for the welfare of coming generations.

Maintenance of Productivity and Protection of the Soil.—A first step in the control of erosion is the maintenance of a fairly high degree of productivity. In much of the humid area of this country, the application of phosphorus (Chap. XV) is generally needed. The addition of potassium, too, particularly on coarse-textured soils, is often a necessary measure. Fruits and vegetables need additions of nitrogen on a rather wide range of soils. Feed crops under some conditions pay for nitrogen in the fertilizer. These suggestions apply to the soils of the humid part of the country rather than to those of the semiarid and arid parts in which plant nutrients are usually more plentiful.

The maintenance of productivity is essential not only from the standpoint of the farmer's income but from the standpoint of protecting the soil as well. Thrifty crops produce more leaf and stem and larger root systems than do poorly nourished crops. The aboveground parts of crops protect the soil against the beating action of raindrops and thus keep the soil from being churned into suspension. Moreover, the rain, instead of striking the soil directly, drips off the plants and is for the most part readily absorbed by the soil. Sealing up of the pores and thus preventing water from percolating into the soil is common on medium- and fine-grained bare soils. Since the protection afforded by plants reduces this clogging of the pores, absorption of water by the soil under crops takes place readily. Thus, less water is free to run off.

In addition, some thrifty crops such as small grains produce more stems or, in other words, stool more than unthrifty ones. And the additional stems during growth and the stubble after harvesting check the movement of water over the soil. Much of the water is absorbed by the soil because the two are held in contact longer than they are on bare soil where runoff is unimpeded. The roots of crops, especially the small grains, grasses, and many of the legumes, hold the soil together. Since thrifty crops produce a network of roots that permeates the soil, they are particularly effective in protecting the soil from erosion.

Crops in Relation to Soil Erosion.—Crops vary greatly in their relation to the erodibility of the soil. Some afford much protection, others very little. A classification based on their habit of growth and management is useful. Under this method of classification, two general groups are recognized: soil-protecting, or close-growing; and soil-exposing, or clean-tilled crops.

Soil-protecting Crops.—In the soil-protecting group are the small grains, wheat, rye, oats, and barley, and the grasses and legumes, grown for either hay or pasturage. These plants are seeded close together and under favorable conditions cover and protect the soil completely. Soil-protecting crops generally are particularly desirable for inclusion in the cropping system on moderately to steeply sloping, erosive soils.

Variations in the degree of protection of the soil exist within this group. In general, the small grains are less effective than are the grasses and more especially the grass-legume mixtures.

One notes in Table 25 the more complete protection given by bluegrass than by wheat. The fall or winter grains give protection in winter, but this is not true of spring grains. In this respect, winter oats and barley may have distinct advantages in the sections in which the winter oats and barley give as large or larger yields than do the spring-sown varieties. Wherever the choice is conditioned entirely by control of erosion, fall wheat may be preferred over the spring varieties. As to the choice between fall and spring wheat, however, climatic adaptations usually determine which is to be grown. The distribution of rainfall may be the determinant between fall- and spring-seeded grains in some areas. For fall-seeded grains, the soil is exposed during late summer and early autumn, and for spring-sown ones during early, mid-, or late spring depending on latitude. If the rainfall is such as to produce more serious erosion in the fall than in the spring period of exposure, this fact may well govern the choice between fall and spring seeding of grain. The good cover and excellent protection of the soil from erosion afforded by winter barley in parts of the Midwest deserve serious consideration.

Among the grasses, those which produce stolons, or underground rootstalks, often produce almost perfect protection both above and under the surface. The bunch types, if grown alone, are less effective, orchard grass and alfalfa (among the legumes) being representative of this group. Seeding grasses with alfalfa, and legumes and fine grasses with the bunch grasses fills the vacant spaces between plants and thus markedly improves the protection of the soil.

In humid areas, a mixture of legumes and grasses produces a more complete and much thicker sward than does grass alone except, possibly, under those conditions where it is feasible to use nitrogen freely. In pastures, the sward of grass alone is often so open as to permit much heaving and consequent erosion in the spring. The growth of inoculated legumes with grasses supplies nitrogen to the latter and thus produces a fairly dense sward. Such a sward resists heaving and gives the soil almost complete protection against erosion.

Cowpeas and soybeans seeded thickly for hay afford good aboveground protection during the growing season. After harvest, however, the soil is left unprotected, except where these legumes are followed immediately with a seeding of winter grain.

Fortunately, this is a common practice in many sections. On some soils, moreover, soybeans bring about an improvement in the physical condition of the soil, which aids in the absorption of water and thus retards erosion.

Buckwheat is a close-growing crop that affords good aboveground cover during its active growing period. Much erosion, however, may occur before the crop is planted. Moreover, the root system and stubble afford but slight protection after the crop is harvested. Buckwheat, therefore is not a satisfactory soil-protecting crop.

Soil-exposing Crops.— Important soil-exposing, or clean-tilled, crops are cotton, corn, tobacco, soybeans (for grain), potatoes, dry beans, peanuts, cabbage, sweet sorghums, broom corn, the grain sorghums, most vegetables, and some other crops. Some variation exists in the protection afforded during growth and in the period of exposure of the soil before planting and after harvesting.

Potatoes, especially late ones, and dry beans leave the soil soft and smooth after harvest. In those sections where such crops come off the land too late for producing a succeeding cover crop, winter and spring erosion is often a very serious matter. In fact, with potatoes this is sometimes the most erosive period of the year in the Northeastern states. In 1936, frozen potato land (1935) lost 1,600 pounds of soil an acre in 10 days under precipitation of 6.57 inches. Frozen grass and clover land lost 7.87 inches of water (partly from snow) but lost no soil. Fortunately, dry beans often are followed by winter wheat, and this crop affords relatively good protection for the soil during winter and early spring.

In their area, the grain sorghums especially when harvested with the combine are rated as affording good winter protection. Broom corn, if not plowed under in the fall, gives almost complete protection. Cornstalks left standing in the field when corn is harvested afford a degree of winter protection. Close pasturing of the stalks, however, materially reduces such protection. Most vegetables are removed completely from the soil and leave little covering for it.

Fruit Crops.—Fruit crops under clean cultivation contribute much to erosion partly because fruits often are not planted on the contour. Changes in management are advisable wherever

FIG. 83.—A South Carolina peach orchard on the contour. This peach orchard near Greer is 38 years old. The rows of trees are on the contour on slopes of 6 to 15 per cent. The trees are vigorous and produce good yields. *(Courtesy of U.S. Soil Conservation Service.)*

FIG. 84.—Contour vineyard at Clemsen, S.C. This method of planting is particularly desirable on steep slopes. *(Courtesy of U.S. Soil Conservation Service.)*

they do not reduce yields and income too drastically. Many apple orchards, for example, are now being fertilized with nitrogen on sod instead of being clean cultivated as formerly. Yields are well maintained under this system, and erosion may be eliminated completely. For fruits that require cultivation, contour planting is advised wherever this is even remotely feasible (Figs. 83 and 84).

Rotation of Crops.—The rotation of crops has many advantages for erosion control as compared with the continuous growing of one or more soil-exposing crops year after year. The comparison between a rotation of corn, wheat, and clover and corn and wheat grown continuously is shown strikingly in Table 25. This rotation was highly effective in conserving the soil as compared with continuous corn or wheat, but it did not compare favorably with bluegrass.

It is notable that continuous corn lost on the average nearly one-third of the rainfall, whereas fallow land lost only slightly more water. The average yearly loss of water from a rotation of corn, wheat, and clover was but slightly more than that from continuous bluegrass pasture, which lost 12 per cent of the rainfall. The losses of soil were heavy on both corn and fallow, especially the latter. The average loss of soil from the rotation was low, as was also that from the bluegrass. Particular attention is called to the figures in the last column of Table 25. These show the number of years that would be required for the removal of the entire surface 7 inches of soil, on the basis of the losses as measured in this work. Corn stands in distinct contrast to the rotation of corn, wheat, and clover. The land that is planted to corn continuously would lose its topsoil in 50 years, in contrast to the rotation land which would lose this quantity of soil in 368 years. In this work, Miller and Krusekopf found that land in continuous corn lost 2.5 times as much water and 4.7 times as much soil as did corn that was grown in rotation with wheat and clover, the corn year of the rotation alone being compared with the continuous corn. Rotation, therefore, strongly favors the saving of both soil and water under Missouri conditions.

The loss from the continuous corn is, of course, extremely high. Society cannot permit such rapid loss of surface soil to continue long over large areas of good land. When the time in which the topsoil is lost from the rotation land (368 years) is considered,

even this appears to be at a more rapid rate than should be permitted to continue indefinitely. Deep soils such as the wind-laid ones of the Midwest may stand such removal of topsoil for a time, but the shallow soils on hardpan, tight clay, or bedrock would be short-lived indeed under such average losses. The general benefits of the rotation of crops are discussed in Chap. XVII.

Contour Tillage and Seeding of Crops.—Conducting all operations of tillage, seeding, cultivation, and harvesting on the contour is an effective means of aiding in the control of soil erosion. Tillage operations and even harvesting leave some depression in the soil. If depressions run up and down or if they angle down the slope, they serve as places for the collection of water and the beginning of gullies. If these furrowlike depressions are on the contour, each serves to catch and hold some water until it percolates into the soil. The ridges made by the cultivator for potatoes, corn, or other crops serve as dams to hold water. Contour potato ridges may hold a rain of more than 2 inches. Where the rows are off the true contour, however, much loss of soil and water may take place.

Musgrave and Norton compared up-and-down hill rows (Fig. 73) with contour ones. Their figures are given in Table 28.

TABLE 28.—LOSSES OF SOIL AND WATER FROM LAND IN CORN, CLARINDA IOWA*

(Average of 1933 and 1935. Average Slope, 8 Per Cent)

Length of slope, feet	Direction of rows	Loss of water		Loss of soil, tons an acre
		Amount, inches	Density, pounds soil per cubic foot	
630	Up- and downhill	2.16	8.11	31.42
315	Up- and downhill	2.65	5.00	24.13
157.5	Up- and downhill	3.55	2.64	17.34
157.5	Rows on contour	0.05	0	0

* MUSGRAVE, G. W., and R. A. NORTON, Soil and Water Conservation Investigations, *U.S. Dept. Agr., Tech. Bull.* 558, p. 51, 1937.

Because of the extremely low runoff in 1934, a year of severe drought, the data for that year are omitted from the averages. Data for 2 years are, of course, insufficient for drawing definite conclusions. The differences, however, between the losses of soil

and water from the up-and-downhill rows and those from the contoured rows are outstanding. The up-and-downhill rows lost 2.16 to 3.55 inches of water in comparison with 0.05 inch from the contoured rows. The corresponding losses of soil were 17.34 to 31.42 tons an acre for the up-and-downhill rows and none whatever during this period from the contoured rows. These data constitute strong argument for contour planting and tillage.

The moisture content of the contour rows averaged for 3 years 2.26 per cent higher than the moisture content in the soil of the up-and-downhill rows, a matter of some importance in dry years.

FIG. 85.—Soil from up-and-downhill rows on Lordstown stony silt loam. These five drums contain soil washed from up-and-downhill potato rows in 1935. The loss was at the rate of 28,000 pounds of soil an acre for the year. Compare with Fig. 86. (*Photographed by A. F. Gustafson on the U.S. Soil Erosion Exp. Sta. near Ithaca, N.Y.*)

As might be expected, the yield of corn was influenced by the direction of the rows. As an average of 2 years, the contoured corn rows yielded 38.1 bushels to the acre. In contrast, the long slope (630 feet) produced 30 bushels, the medium (315 feet) 27.9 bushels, and the short slope (157.5 feet) 23.2 bushels of corn to the acre. All this comparison was made on a slope of 8 per cent on an absorptive soil. On the U.S. Soil Conservation Experiment Station near Ithaca, N.Y., up-and-downhill potatoes on a slope 311 feet long produced as an average for one wet and

one dry year, 1935 and 1938, 23 fewer bushels potatoes than were grown on the contour under essentially identical conditions. In the dry year (1938), the increase was 36 bushels of potatoes to the acre on the contoured rows. The loss of soil from the up-and-downhill potatoes was more than 28,000 pounds in 1935 and more than 10,000 in 1938, or an average of about 19,000 pounds to the acre; on the contoured rows, the loss was about 100 pounds to

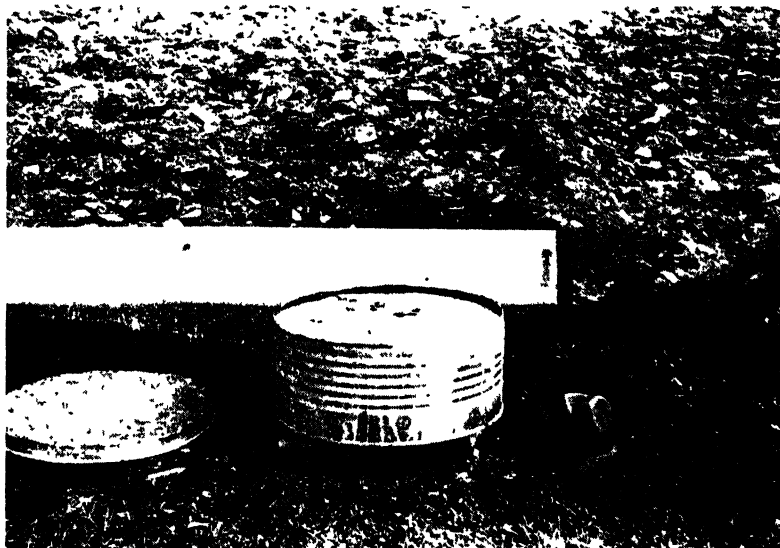



FIG. 86. Soil from contour potato rows. The shallow container at the left holds soil lost at the rate of 202 pounds to the acre from contour potato rows in New York. Compare with Fig. 85.

the acre on the average, or only $^{1}/_{200}$ as much as on the up-and-downhill rows (Figs. 85 and 86).

The plants themselves, particularly close-growing crops on the contour, help to check the flow of water and consequently to encourage its absorption by the soil. It is worth while to have meadow seedings on the contour for this reason.

Strictly Contour Rows Desirable.—The necessity for keeping the rows of clean-tilled crops on the true contour often is not appreciated. Each ridge acts as a dam and holds water in a long narrow pond. Such a field after a heavy rain presents the appearance of water standing on a hillside.

If a dip occurs in the rows where they cross an old partly filled gulley, water flows into it from both directions. Potato ridges are seldom much more than 6 inches high. If the slope in the rows is 1 per cent, water ponds over a distance of 50 feet in each direction from the low point, 25 feet on a 2 per cent slope. If rows slope 3 or 4 per cent, or more, the depression is soon filled; and if rain continues, breakover of the ridges is inevitable. Usually the next row downhill has about the same fall and, consequently, a similar concentration of water; it therefore, has all the water it can hold. Water breaking over from above, then, causes a breaking of many ridges below. Only if the slope flattens out and the rows return to the true contour quickly is gullying down the slope avoided. According to this viewpoint, a slope of as little as 1 per cent in rows of clean-tilled crops over a distance of 50 to 100 feet from both directions may cause gullying during heavy rains. Farmers in some demonstration areas are quick to note the damage by washing that is caused in this manner and to ask that their rows be laid out strictly on the contour. Only in this manner can gullying be prevented in potatoes. And it is even more essential that the rows of crops such as corn, tobacco, field beans, and vegetables be planted on the true contour; for little ridging is advisable with these crops, and hence little ponding of water occurs. Since it is not held, the excess water goes off over the surface, and loss of topsoil usually occurs.

In some areas, rainfall is so heavy that even true-contour potato ridges or crops similarly ridged cannot hold the water. Many crops are grown on slow-draining soils. In the event of heavy autumn rainfall, the soil in level rows may become too wet for harvesting a crop such as potatoes. Under these conditions, it is probably better to give the rows a uniform slope of 1 per cent or somewhat less, depending on soil conditions. It will obviously be necessary to provide for the collection and safe disposal of the water at the ends of the rows. Where conditions are favorable, sloping the rows in both directions from the middle of the field may be desirable, for this arrangement reduces by one-half the quantity of water to be taken care of in one place.

Grass-covered Waterways.—Farmers have long recognized the protective effect of grasses and have used them in waterways (Fig. 87). This practice can well be extended to depressions in contour rows, particularly to depressions that otherwise require

very sharp bends in the rows. It is far better to leave grass or to seed grass in such places than to permit a continuation of gullying. To be effective, the grass should cover all the depression and somewhat more on the sides. If too narrow, washing often occurs on both sides of the grass. Tillage operations across the grass should be carried out so as not to destroy it. Where the grass is of sufficient width, it may be harvested for hay. The usual

FIG. 87.—A grassed waterway in Illinois. The hay is being harvested from a grassed waterway between oats and corn. The grass protects the soil from the erosive action of water that goes down this depression. (*Courtesy of U.S. Soil Conservation Service.*)

meadow mixtures or those suggested for diversion ditches (page 212) are useful in grassed waterways.

Contour Strip Cropping.—Contour strip cropping is an old practice. Its exact origin is probably unimportant, but it may have started in Switzerland. It seems clear, however, that farmers themselves conceived the idea of strip cropping in a number of separate areas and laid out their farms in strips that were near the contour.

In 1885, Beyer laid out the farm that was operated for many years by the late William R. Linnert near Danville, Pa., in contour strips, doing his work by means of a carpenter's level (Fig. 88). The land has been farmed in accord with this contour strip

layout since that date. The strips have controlled gullying so that none is in evidence, whereas adjacent similar, or less steeply

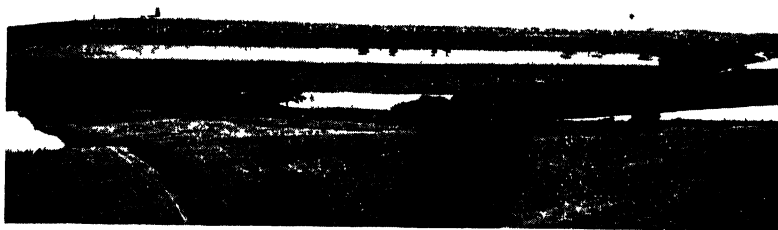



FIG. 88. Early strip cropping in central Pennsylvania. This strip cropping was laid out on the farm of the late Wm. R. Linnert in 1885. The 1939 crop therefore was the 55th grown in this system of cropping. The boundaries between the strips were determined by means of a carpenter's level. Checking with a hand level indicated that the strips are strictly on the contour. Some strips are three quarters of a mile in length. No gullying was in evidence on this land but it was rather bad on adjacent unstripped land at the left. Photographed in 1939.

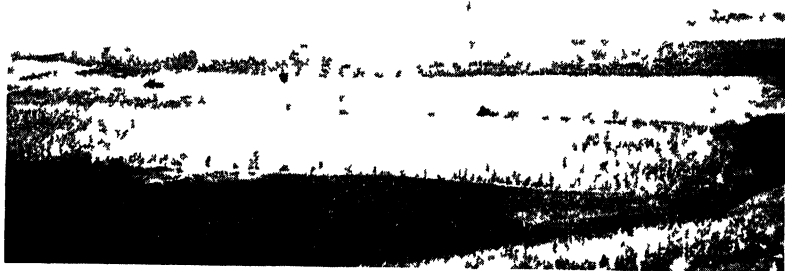



FIG. 89.—Early strip cropping near Washington, Pa. The strip with the corn shocks extends completely around this chocolate drop hill. These strips are near but not precisely on the contour at all points. Strip cropping in this locality has been practiced since early in the present century. Photographed in 1939.

sloping, land of the same soil type has undergone severe sheet erosion and some gullying. Crop yields have held up well on the

Linnert farm and on a number of other farms that were laid out later by Beyer and neighboring farmers.

Strip cropping is being practiced on many of the farms in Mayberry Township on the south side of the Susquehanna River near Danville. According to the owner of one of these farms, it has been operated in strips that are near the contour for more than 25 years. Many farms have been strip cropped in the three

FIG. 90. Air view of field strip cropping in Washington County, Pa. A high proportion of the cultivated land is being farmed under a system of contour strip cropping. This was developed and laid out by the farmers themselves and has been practiced for 30 years or more. (*Photograph by Agricultural Adjustment Administration.*)

extreme southwestern counties of Pennsylvania, also. Contour strip cropping is reported to have been started there soon after 1900 (Figs. 89 and 90).

A few miles north of Jersey Shore, Pa., is the farm of Ulmer Brothers. Some years ago, a thundershower caused much surface washing and severe gullying on their farm. After surveying the damage and noting the direction of the gullies, the owners laid their farm out in strips at right angles to the gullies. If the location of the gullies was natural, that is, following the slopes

and not man-made depressions, the strips thus placed would be on the contour. Thus, they laid out strips of uniform width from one end to the other, their longest strip being more than ½ mile in length. Ulmer Brothers liked their system of strip cropping and have farmed with substantially the original layout for the past 25 years. Strip cropping has spread between this farm and Williamsport, Pa., until it is said to embrace nearly all the crop land on about 100 square miles.

FIG. 91.—Strip cropping in New York. At the left is strip cropping on the farm of Fred Towner in Steuben County, N.Y., that was started about 1920. These strips extend to the left all the way across the Towner farm. The strips are somewhat wider than are used today, yet they have eliminated gullying and have markedly reduced sheet washing. Note the numerous gullies on the right of the hedge row (near center). These resulted from a single rain which caused no severe gullying on the Towner farm.

In New York, strip cropping has been practiced in several isolated places for some years. Towner in Steuben County started strip cropping independently much as did Ulmer Brothers in Pennsylvania. He has farmed his strips practically as laid for the past 20 years (Fig. 91).

Nygard and Bullard[1] report on old strip cropping in Minnesota. They found that the late A. Von Arx, a Swiss farmer, had practiced strip cropping for 61 years. Corn was alternated with

[1] NYGARD, I. J., and L. E. BULLARD, Effect of Erosion on Long-time Strip Cropping in Bush Valley, Minnesota. *Soil Conservation*, Vol. 4, pp. 239–241, 1939.

strips that were left in grass for some years. The width of the corn strips was 75 feet on the steeper slopes. Strips 90 feet wide were used on slopes of 10 per cent. On slopes of more than 3 per cent, corn was never grown in successive years, but the land was sown to oats after corn and seeded back to meadow at once. Records show that yields are consistently higher on this than on adjacent land that has been farmed in the usual "square" way. The absence of gullies on the Von Arx farm was notable as com-

FIG. 92.—Strip cropping in West Virginia. These strips are 60 feet wide on a slope of 23 per cent. Both sides of the strip are on the contour. The rotation is corn, wheat, and 3 or 4 years of alfalfa. Clover and timothy or other hay mixtures may be used in the place of alfalfa. (*Courtesy of E. C. Weitzel, Soil Conservation Service.*)

pared with the large number of gullies on similar land that had not been strip cropped. Some spread of strip cropping has occurred in the neighborhood.

Strip cropping in Belmont County, Ohio, is said to have been started around 1870. The practice has spread to such an extent that a definite comparison has been made between the income on strip-cropped farms and that on similar topography on the same soils that have been farmed in the usual manner. The author has noted distinct evidences of a fair degree of prosperity on strip-cropped farms in comparison with that on similar land

that was managed differently. Strip cropping has been carried on also near Wheeling, W. Va.

This early strip cropping was a commendable beginning of an excellent practice for keeping the surface soil on the farm. To be successful, it must be reinforced by good soil management. Some of the strips in the early work were off the contour in places, and this led to some gullying. Moreover, the evidence is that strips narrower than the early ones in Pennsylvania may be

FIG. 93.—Air view of the Sweitzer Creek watershed in southern New York. This view shows the field layout before the work of the Soil Conservation Service was begun. Although there is some evidence of contour farming many fields are nearly square in shape. (*Courtesy of U.S. Soil Conservation Service.*)

expected to give better control of erosion (see Fig. 92). Strip cropping is one of the leading means for controlling erosion on sloping lands on which soil-exposing crops are grown (Figs. 93 and 94).

The Width of Strips.—Many factors, such as the erodibility of the soil, the relative erosiveness of the crops being grown, the rotation, the number of clean-cultivated crops grown (or the proportion of the land in clean-cultivated crops), the slope of the land, the absorptive capacity of the soil, the climate, and the amount and intensity of the rainfall should have consideration in determining the width of strips.

It appears that for some time it will be necessary to rely on observations because of the difficulty of determining experimentally the width of strips that give the most practicable control of erosion under the multitude of possible combinations of the conditions just mentioned. Experience has indicated the advisability of narrower strip widths than were used in 1936 and 1937 in New York. This is partly owing to the amount of erosion on

FIG. 94.—Later view of the Sweitzer Creek watershed in southern New York. Much of the land in the watershed was being managed under a plan for the conservation of water and soil when this picture was taken five years after Fig. 93. It is notable that strip cropping is the general practice in this area in which potatoes are an important crop. (*Courtesy of U.S. Soil Conservation Service.*)

strips that lie essentially without protection throughout the winter and early spring.

Some experimental results from strip cropping in comparison with up-and-downhill and contour planting are available. Lamb and his associates have reported data from the U.S. Soil Conservation Experiment Station in southern New York. These data follow in Table 29.

This work does not cover a period long enough to warrant final conclusions; yet the differences are so great as to suggest their having real value.

In the first place, the strips 100 feet in width on the slope of 15 per cent on Lordstown flaggy silt loam, a well-drained soil, were as effective in holding soil and water as 50-foot strips. The

6-year rotation under field conditions is undoubtedly more effective in holding the soil than the 3-year one. Potatoes in rotation planted up- and downhill lost far more soil than did either the contoured rotation or the same rotation strip cropped. In 1936, a heavy rain fell before the oats had made sufficient growth to protect the soil. This caused a loss of nearly 2,800 pounds of soil an acre from the oats seeded up- and downhill on a slope 311 feet long. Oats on the contour on the same slope lost 2,300 pounds of soil from the same rain. Though admittedly inadequate, these data indicate the superiority of strip cropping over planting entire slopes to the same crop in a rotation that includes soil-exposing crops.

TABLE 29.—COMPARISON OF STRIP CROPPING WITH UP- AND DOWNHILL AND CONTOUR PLANTING*
(Average for 3 years)

Width of strip,† feet	Management—rotation: potatoes, oats, clover	Losses	
		Water, inches	Soil, pounds an acre
51.8	Strip cropped	0.10	115
103.6	Strip cropped	0.14	97
51.8	Strip cropped‡	0.21	24
311.2‡	Up- and downhill	1.15	10,356
311.2‡	On the contour	0.38	835

* LAMB, JOHN, JR., and associates, *U.S. Soil Conservation Exp. Sta. Results* 1935 to 1938, N.Y.R. 39, p. 10, 1939.

† The upper third of these strips has a slope of 8 per cent and the lower two-thirds, one of 15 per cent.

‡ Rotation: potatoes, oats, clover, hay, hay, hay.

Provisional strip widths for use under the specific conditions stated are given in Table 30. In this arrangement, both slope and erodibility of the soil are given consideration. In areas where the type of rainfall is particularly conducive to erosion, the widths given for soil condition 2 may be applied to soil conditions that actually correspond to 1. Likewise, widths for 3 may be applied to the soil conditions stated under 2.

According to Table 30, strip widths are varied 5 feet for each unit of increase or decrease in the percentage of slope. This provision is based on observations rather than experimental data.

Though it is believed to be a step in the right direction, the author stands ready to revise it in accord with sufficient experimental data. The farmer and those who advise him must apply their own best judgment to individual conditions.

TABLE 30.—PROVISIONAL APPROXIMATE STRIP WIDTHS FOR VARYING SLOPE AND SOIL CONDITIONS

Slope, per cent	Soil conditions		
	1. Well-drained, resistant to erosion, feet	2. Medium drainage, moderate erodibility, feet	3. Poor drainage or water-laid soil, easy erodibility, feet
3	135*	110*	85*
5	125	100	75
8	110	85	60
10	*100*	*75*	*50*
12	90	65	
15	75	50	
17	65		
20	50		

* It is probable that the widths given for the 5 per cent slope, especially for conditions somewhat less favorable than those indicated, should be the maximum width used.

It is not advised that strip cropping often be practiced on slopes steeper than 20, 15, and 10 per cent, respectively, for the three soil categories shown in Table 30. Steeper land, however, is farmed to these general types of crop, but it is difficult to hold the soil in place when that is done.

Slopes gentler than 5 per cent may not always require strip cropping. Strictly contour farming, under favorable conditions with respect to erodibility, may afford good control, especially if cover-crop protection can be provided for the winter season. On the other hand, it is difficult to work out a good crop arrangement and to maintain the desired acreage of each crop every year, if one field, perhaps a relatively level one, is four or five times the acreage of the average-sized strip.

Arrangement of Crops on Strips.—Care is required in working out the arrangement of crops on strips. Plowing two adjacent strips at one time is not advisable. A satisfactory arrangement of crops on strips is given in the following tabulation.

STRIP-CROP ARRANGEMENTS

Strip	First year	Second year	Third year	Fourth year
First field or series of strips				
1	Potatoes	Oats	Clover	Timothy
2	Clover	Timothy	Potatoes	Oats
3	Potatoes	Oats	Clover	Timothy
4	Clover	Timothy	Potatoes	Oats
5	Potatoes	Oats	Clover	Timothy
6	Clover	Timothy	Potatoes	Oats
7	Potatoes	Oats	Clover	Timothy
8	Clover	Timothy	Potatoes	Oats
Second series				
9	Oats	Clover	Timothy	Potatoes
10	Timothy	Potatoes	Oats	Clover
11	Oats	Clover	Timothy	Potatoes
12	Timothy	Potatoes	Oats	Clover
13	Oats	Clover	Timothy	Potatoes
14	Timothy	Potatoes	Oats	Clover
15	Oats	Clover	Timothy	Potatoes
16	Timothy	Potatoes	Oats	Clover
Small farm				
1	Potatoes	Oats	Clover	Timothy
2	Timothy	Potatoes	Oats	Clover
3	Oats	Clover	Timothy	Potatoes
4	Clover	Timothy	Potatoes	Oats
5	Potatoes	Oats	Clover	Timothy
6	Timothy	Potatoes	Oats	Clover
7	Oats	Clover	Timothy	Potatoes
8	Clover	Timothy	Potatoes	Oats
Three-year rotation				
1	Potatoes	Oats	Clover	
2	Oats	Clover	Potatoes	
3	Clover	Potatoes	Oats	
4	Potatoes	Oats	Clover	
5	Oats	Clover	Potatoes	
6	Clover	Potatoes	Oats	

Any intertilled crop may take the place assigned to potatoes in these rotations. Oats merely represents a grain crop; clover, a biennial or perennial legume; timothy, any grass for hay.

A 3-year rotation of this general type is undesirable in strip cropping because the grain crop (oats) and the clean-cultivated crop (potatoes) so often occur on adjacent strips. During a period in early spring in the Northeastern states, both strips are bare and subject to severe erosion. A 6-year rotation of a cultivated crop, grain, clover, grass, grass, grass, may be better than a 4-year one under the conditions that prevail on many hill lands, provided, of course, that the livestock on the farm is sufficient to consume the additional hay produced. A 5-year rotation in place of the 3-year one makes possible the separation of the strips in potatoes and oats and makes for a marked reduction in losses of both soil and water.

Objections have been raised to strip cropping. Some time may be lost in tillage operations, but this loss is more than offset by the economy in power. This saving has been found to be 6 to 10 per cent.[1] Moreover, the saving of soil and nutrients and the higher yields obtained on contour strips have confirmed the economy of farming sloping lands in this manner.

It may be noted that Table 30 suggests *approximate* strip widths. The width should be adjusted to fit the more important machinery which in some sections may be the two-row potato digger, in others the two-row corn harvester, and elsewhere the two- or three-row cultivator. Smaller implements and admittedly somewhat less efficient ones, perhaps, may serve better on sloping lands and be of material service in conserving the soil.

Contour Furrows.—Contour furrows are being used in pastures for the purpose of holding water. Even in humid areas, water is lost from sloping pasture lands. And nearly every year droughts of varying intensity and duration reduce pasture yields. Saving moisture, therefore, by means of contour furrows increases production during prolonged dry periods. In humid areas, the ordinary turning plow is used (Fig. 95). An effective furrow for holding water may be made by first throwing a shallow furrow downhill and then plowing a deep furrow into the shallow one. The second furrow slice overfills the first furrow and produces a

[1] BARGER, F. L., Fuel and Time Requirements of Contour Farming, *Agr. Eng.*, Vol. 19, pp. 153–157, 1938.

FIG. 95.—Contour furrows in a pasture in Ohio. Such furrows may be made with the ordinary turning plow. Furrows introduce a disadvantage from the standpoint of mowing pastures. The saving of water for the grass and holding it out of the valleys in time of floods may justify the use of such furrows. (*Courtesy of U.S. Soil Conservation Service.*)

FIG. 96.—Contour furrows in Texas. These furrows are for the purpose of holding water. All of the rain water is needed for the pasture. Moreover, keeping the soil moist prevents it from blowing. (*Courtesy of U.S. Soil Conservation Service.*)

dam that gives good water-holding capacity except on very steep slopes. A given depth of furrow has less capacity on steep than on gentle slopes because the soil thrown out of the furrow moves downhill farther and forms a lower dike or dam.

Similar furrows are used in reforestation, the seedlings being planted in the furrow. Contour furrows are used also in the drier areas that receive high-intensity rains for reducing the amount of quick runoff and consequently for minimizing the crest of floods and saving water for the use of crops (Fig. 96).

Fig. 97.—Diversion ditch in southern New York. The channel is 8 feet wide and 17 inches deep. The slope in the channel is 1 per cent. This ditch carries the runoff water from 12.5 acres of slow-draining land on a slope of 6 per cent above it. The diversion of the water protects a steeper slope of well-drained soil on the lower side of the ditch.

Diversion Ditches.—On long slopes, ditches are used for diverting the runoff water from cropland to forest, meadow, or pasture land or to a stabilized stream channel. Diversion ditches collect water and conduct it slowly and safely to a previously stabilized outlet. A perfectly safe outlet is the first requirement in the utilization of diversion ditches in the control of erosion. Unless one can be found or can be developed at reasonable cost, it is far better to keep the water spread out over a slope than to collect it in a ditch.

On farm lands, a type of diversion ditch that may be crossed at any point with all the ordinary farm implements is most desir-

able (Fig. 97). A broad, flat-bottomed channel seeded to adapted, erosion-resisting grasses and legumes is highly satisfactory, the product being harvested regularly for hay. The

FIG. 98. A terrace-channel outlet in North Carolina. Here an outlet is in the process of development. The lower part of it has been sodded. Note the flare which is for the purpose of spreading the water. Spreading the water reduces its cutting power. A strip of grass above the terrace channel will aid in keeping it clear of sediment. (*Courtesy of U.S. Soil Conservation Service.*)

construction of these ditches is treated under Terraces in the succeeding paragraph.

Terraces.—Terraces[1] are in effect sidehill, or diversion, ditches. Their purpose is to collect water on cropped slopes and to carry it at low grade to safe outlets where the concentration of water

[1] See "Soil Erosion and Its Control," Chaps. V IX, by Quincy C. Ayres, McGraw-Hill Book Company, Inc., New York, 1936, for complete information on terraces and especially their construction. See also "Conservation of the Soil," by A. F. Gustafson, Chap. XI, McGraw-Hill Book Company, Inc., New York, 1937; "Land Drainage and Reclamation," Chap. XXII, by Q. C. Ayres and Daniels Scoates, McGraw-Hill Book Company, Inc., New York, 1939; and "Soil Conservation," Chap. XX, by H. H. Bennett, McGraw-Hill Book Company, Inc., New York, 1939. The U.S. Department of Agriculture and many state colleges of agriculture have issued publications dealing fully with terracing for their particular sections.

can do no damage. A protected outlet must be found or developed before it is safe to collect water in terrace channels (Fig. 98).

Terraces are of several types: bench; level, or closed-end; and diversion, or channel, represented by the Nichols and Mangum terraces.

The bench terrace has a nearly level surface with a rather steep outer face. It is conceivable that the bench terrace with a sod or stonewall face may be an ultimate development, even in this country, as agriculture matures and becomes fully stabilized.

Fig. 99. A terrace in Missouri. This terraced field was seeded to winter barley which was being grazed in November. The barley rows are parallel to the terrace embankment. (*Courtesy of H. M. Dail, Missouri Agr. Exp. Sta.*)

A small ditch or even tile may be used for conducting surplus water away to safety.

Closed-end terraces are used in pastures in much the same way and for the same purposes as contour furrows. These terraces are level from end to end; otherwise, the concentration of water in them may cause gullying.

The diversion type of terrace appears to be a development from an early, single plow furrow made to carry water from cropped slopes. In 1885, P. H. Mangum in North Carolina developed from the previously used narrow types the broad-base, broad-channel type of terrace to which his name has been applied. He developed the channel and embankment by moving soil from both

FIG. 100.—Terrace construction. This terrace is being built with moderate-sized equipment, the embankment being built up from the upper side. (*Courtesy of Caterpillar Tractor Co.*)

FIG. 101.—Terrace care. Terraces and diversion ditches require attention. This terrace in Virginia was subjected to a rain of 5½ inches in 1 hour. The condition shown here was to be expected. After heavy rains any deposit in the channel must be cleared out; otherwise there is danger of overtopping and cutting out of the channel. (*Courtesy of U.S. Soil Conservation Service.*)

above and below the middle line of the embankment. Some of the early terraces were built without the right fall at all points, and breaking over and gullying followed. Properly constructed, with the right slopes and protection, the Mangum terrace has given good results.

The Nichols terrace is the latest development (Figs. 97, 99, and 100). All of the soil for the embankment is taken from the channel and none from the lower side. This arrangement produces a channel about 12 inches deep that is independent of the embankment which increases the channel depth to about 18 inches. If breaking over of the embankment occurs, the channel continues to function to some extent. Repair, therefore, is much less costly with this than with the Mangum type of terrace (Fig. 101).

The distance between terraces depends on many of the factors that influence the width of strips (pages 204 to 207). Intensity of rainfall is a highly important factor, and terrace channels as well as ditches should be of ample size to carry the surplus water. Terraces and diversion ditches should be planned by those trained in the use of the level and who have had the desired experience in such work. Not only must the terrace system be devised but the terrace construction should be supervised, and the finished system duly checked by an agricultural engineer. Too great or too little slope in the channels and the outlets can lead to serious trouble. Properly spaced and rightly built terraces are of real service in the control of losses of both soil and water.

Terracing is usually inadvisable on slopes steeper than 12 per cent, and it is better to confine it to slopes of 10 per cent and less. Other utilization of the steeper slopes, such as for meadow, pasture, and even forest for a few decades may be better. When needed for cultivated crops, the land in meadow, pasture, or forest may be brought back into cultivation and then cropped as the needs of the population may determine.

The Control of Gullies.—Gullies result from the concentration of water in depressions on slopes. The depressions may be natural ones, or they may result from tillage operations. Dead furrows are representative of the depressions resulting from tillage. Wheel tracks, paths made by livestock, and the runs of rodents, also may lead to gullying.

Whatever their cause, gullies must be brought under control soon after their formation, otherwise, they often attain such size that the expense of filling them becomes prohibitive. Gully prevention is far better than gully cure. Keeping the soil level, or without depressions down slopes, and keeping part of a slope in soil-protecting crops help to prevent the runoff water from collecting in depressions. If the concentration of water in depressions can be avoided, gullying will be avoided. Diversion ditches, terraces, and contour strip cropping are useful preventive measures.

FIG. 102. Brush and trash check gullying in Iowa. Anything that slows down the velocity of the current checks gullying by reducing its cutting power. The trash often brings about deposition of sand and silt and thus in time fills gullies. The posts and stakes hold the brush in place. The use of live willow stakes and slips of other sprouting woods such as elderberry and cottonwood is often advisable. (*Courtesy of U.S. Soil Conservation Service.*)

After breaking down the edges of gullies, the sides and bottom may be seeded to grasses and legumes. The covering of the more actively eroding bottoms and sides with sod, manure, or straw is a useful expedient in many places (Fig. 102). The use of manure or straw as a mulch aids in obtaining a cover by seeding grass and legume mixtures.

Various native shrubs and trees can help greatly (Figs. 103 and 104). Preference may well be given to the species that are most useful to wild life if these are equally effective in gully

Fig 103 Gully treatment in Illinois The steep sides have been sloped and planted to locusts Photographed in 1934 (See Fig 104) (*Courtesy of U S Soil Conservation Service*)

Fig 104 Gully controlled by vegetation Same situation as shown in Fig 103 2 years later 1936 By then excellent growth in this type of situation the locusts have brought this gully under control The growing leaves prevent the beating action of the rain on the soil and the fallen leaves cover and protect it during winter and spring (*Courtesy of U S Soil Conservation Service*)

control. Vines are especially useful. The Japanese honeysuckle grows well in the subsoil of gully banks and soon establishes complete protection (Fig. 105). Kudzu in the South is especially effective because it is a legume and, if inoculated, can establish itself where nonleguminous plants fail. The transplanting into gullies of wild blackberries, raspberries, elderberries, hazel brush, wild crab, and other fruit and nut bearers in their habitat is helpful. Black, or common, locust, if inoculated, grows well on

FIG. 105.—The Japanese honeysuckle protects the soil. The Japanese honeysuckle grows on unproductive, raw soils and in time affords complete protection. It may be used on road, ditch, or gully banks. Under very favorable conditions it becomes a nuisance in that it grows on fences and overruns shrubs and even small trees. In the northern part of its area, however, it gives little trouble. Photographed near Ithaca, N.Y.

gully banks and may be of great aid where it is adapted. Moreover, the nitrogen fixed by the locust encourages the growth of grasses under it and thus affords still further protection. Fencing out livestock helps vegetation to effect control.

Various types of check dams—woven wire, brush, log, stone, concrete—are used to aid vegetation in establishing itself. The expense of dams is the difficulty. Gullied land is seldom very productive, and a farmer often cannot use funds derived from other land for restoring or even saving gullied land. Stones carefully placed in gullies so as to cover the raw soil often prevent further cutting.

A practicable, inexpensive method of controlling moderate-sized gullies is the use of straw and brush. Wet straw is first placed in the bottom and on the sides of a gully whose sides have been sloped somewhat. Brush, preferably cut recently, is packed in the gully with butts upstream and fastened down with posts and poles. Wet straw is then packed among the butts to improve its filtering effect. Rocks and stones may be used instead of poles for holding the brush down. Driving stakes or slips of such sprouting woods as willows, poplar, elderberry, and others

FIG. 106.—Reservoir filled in Pennsylvania. (*Courtesy of U.S. Soil Conservation Service.*)

into the bottom of the gully in time produces a live dam so that when the brush decays live material is present to hold the soil. Dams and live material should extend well up on the sides of gullies so as to prevent washing around the ends of the dams.

Silting of Reservoirs and Its Control.—Reservoirs in farming sections are filling with sediment very rapidly (Fig. 106). In forested areas, reservoirs function for long periods. In contrast, reservoirs in sections that produce considerable areas of clean-cultivated crops are filling in 14 to 50 years. Such rapid filling means great loss to the public in general, for good sites for new dams are seldom available. Growing fewer acres of clean-cultivated crops, protecting the more sloping lands, improving the sward of meadows and pastures, reforesting the steepest and

worst-washed soils, and protecting stream banks and channels might do much to prolong the life of reservoirs.

Agriculture and the Alleviation of Floods.—The methods mentioned in the preceding paragraph might be of value in holding the water longer on the land. More of it would soak into the soil, less of it therefore would be free to rush into the streams and flood the valleys. Somewhat general use of contour furrows

FIG. 107. Keeping the soil rough. By means of the damming lister stubble land may be kept rough. It is always desirable to have all crop rows planted and all tillage done at right angle to the direction of the prevailing winds. Sometimes doing this results in varying degrees of slope in the furrows which may lead to erosion. Such loss of water and erosion may be overcome by the use of damming devices. Leaving some of the stubble exposed aids further in holding the soil. (*Courtesy of John Deere, Moline, Ill.*)

in pastures and level or closed-end terraces might keep much water out of the valleys for a time and permit it to reach the streams slowly through springs as in the days before the white man settled this country. Once in the valleys water is hard to control. Detention dams are being built for holding floodwater back from the larger valleys and releasing it slowly after the normal floodwater has passed on toward the sea.

THE CONTROL OF WIND EROSION

Many principles apply alike to the control of water and of wind erosion. The most important ones that have a direct

bearing on the control of wind erosion are discussed in this section.

Maintenance of Soil Cover.—Blanketing the soil with vegetation is equally important in the reduction of soil movement by wind as in the reduction of soil movement by water. A good grain stubble greatly reduces the velocity and, therefore, the power of the wind to move the soil. The more complete the cover, the less the wind can move the soil. Lands in the Great Plains that have been badly damaged by blowing may be

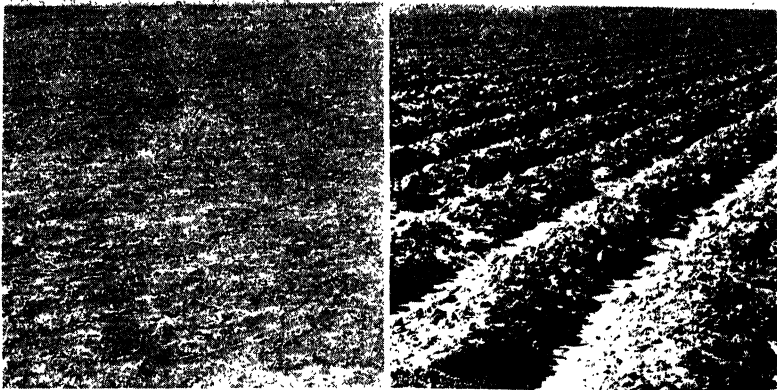



FIG. 108.—Controlling blowing of sand. At left: before listing, the surface is smooth and subject to blowing. At right: the same area after listing, the surface is rough and in excellent condition to check sand movement. The sand blown from the lister ridges is caught in the furrows. (*Courtesy of A. F. Swanson, Bureau of Plant Industry and Kansas Agr. Exp. Sta.*)

reclaimed by reestablishing a vegetative cover during periods of ample moisture. The native grasses are highly effective for this purpose.

Maintenance of a Rough Surface.—Incoherent sand or dry, finely pulverized loams and silt loams are subject to easy movement by wind of even moderate velocity. As indicated in the previous chapter, implements that pulverize the soil must be avoided. The surface is best kept rough and cloddy with as much of crop residues as possible mixed with the upper-surface soil (Figs. 107, 108, and 109). The soil ought never to be left

through the winter without as good a cover of vegetation as possible. If the surface is protected, the soil as a whole is saved from wind erosion.

Direction of Tillage and Seeding.—Tillage and seeding for the control of wind erosion are best done at right angles to the direction of the prevailing winds, for obvious reasons. In the case of grain, an occasional cross-seeded strip is advisable, for the wind

FIG. 109.—Lister furrows catch sand. This field had been lister-furrowed and was in good condition for the control of blowing. The adjacent field at right had not been treated and is contributing sand. This is being caught in the lister furrows. When they are filled blowing will begin. As with many phases of soil conservation the control of blowing is a matter of deep community interest. (*Courtesy of A. F. Swanson, Bureau of Plant Industry and Kansas Agr. Exp. Sta.*)

frequently shifts in direction in some places. Wind action along rows of grain may be very marked, whereas rows across the path of the wind check its movement to a considerable extent.

Strip Cropping.—Strip cropping, like seeding, is done at right angles to the prevailing wind direction. Cropped strips are alternated with fallow ones, or soil-protecting crops are alternated with soil-exposing ones. Strips of grain alternated with fallow afford considerable protection to the latter. Soil blown from the

fallow land is caught and held in the strips of grain. If the fallow strips are wide enough to give the wind sufficient chance, soil caught in the grain may form a ridge and in extreme cases may even cover and smother the grain. In that event, the grain fails in its purpose. Because of the tendency to ridge formation in the grain on the windward side of the strips, it is well to move the strips back and forth enough to keep the land surface relatively smooth. The grain in the later stages of its growth serves to reduce blowing by means of its effect as a windbreak.

Windbreaks.—Wherever trees thrive, they may be used effectively as windbreaks. Windbreaks check wind velocity for a considerable distance to the leeward and not only check actual soil movement but reduce evaporation and raise humidity. Lessened evaporation and increased humidity enable crops to produce larger yields in the zone protected by the windbreak. Some land is wasted because the trees shade the soil and use up the available water. The proper distance between windbreaks varies considerably with local conditions.

On the Great Plains, care should be exercised to plant only trees that are adapted to prevailing conditions. The failure of unadapted trees ruins the windbreak, particularly if some trees die after others are large enough to be of considerable service. Replacing dead trees delays their reaching a size that enables them to function with the other trees in the windbreak.

In planting a windbreak, low, thick-growing trees or shrubs are used at the outside; taller, dense-topped trees are set next; and the tallest are set in the middle. This arrangement checks the wind effectively from the surface of the soil to the top of the tallest trees. The use of various evergreens (conifers) is essential to give an effective all-year-round windbreak. Deciduous trees are ineffective during the period in which the leaves are off.

Furrows.—On level land, furrows at right angles to the prevailing wind direction catch and hold snow, and water from rains as well (Fig. 96). On sloping land, the furrows still must be kept across the path of the wind. On slopes, therefore, the basin lister is preferable to the regular lister. The dams made by the basin lister prevent the flow of water down the furrows and thus conserve it from both rain and snow. Moreover, since the water held keeps the soil moist, it also prevents blowing, for only dry soil blows.

Control of Blowing of Sand in Humid Areas. Many crops on sand and sandy loams are injured by blowing sand. Covering the soil with vegetation controls this movement. The principles of control of blowing of soils in the Great Plains hold in general for sands in humid areas. Legumes are important. Among them are the trailing wild bean (*Strophostyles helvola*) and the black locust, and in addition the nitrogen-gathering partridge pea (*Cassia Chamaechrista*). The latter thrives on dry, sandy land and holds it against blowing. Mixing these and other nitrogen-gathering plants with grasses often improves the control. The

FIG. 110.—American beach grass on Long Island. Since the storm of 1938 much beach grass has been planted for controlling sand movement on the outer part of Long Island, N.Y. It had been used along the roads leading to Jones Beach near Brooklyn for some years with good results.

locust and other trees may be alternated in belts in order to give the nonleguminous trees some of the nitrogen fixed by the leguminous ones.

American beach grass (Fig. 110) is often hand planted for the protection of roads, residences, or parks. Plantings of this kind are relatively costly, and the grass alone is not a complete success. Much of it on Long Island, N.Y., is dying. Seeding the trailing wild bean or partridge pea along with the beach grass should help greatly to keep the grass growing.

Picket fences are in use on the Atlantic shore of Long Island. As a temporary expedient, they are a success in holding blowing sand. As the sand covers them, the fences will have to be lifted and this procedure repeated as the sand piles up. Vegetation will be needed to bring about complete stabilization of such sands.

Control of Blowing on Peaty Soils.—As shown in the preceding chapter, crops suffer considerable injury on peaty lands from wind erosion. In New York, for example, blowing of peat occurs in May and June. The pieces of wood or dry, hard, colloidal peat are hurled against the tender plants and in time kill them. Windbreaks of willow have been planted at regular intervals in the peat areas. As additional aids in checking peat movement, picket fences are sometimes used and burlap is placed on them near the ground to improve their effectiveness. Rye sown the preceding fall attains considerable height before the blowing season. In strips of one or two drill widths, this crop serves effectively as a low windbreak. When ripe or when no longer needed, it may be harvested or plowed under. The land that it occupied may then be planted to a medium- to late-season crop. Thus the land occupied by the rye windbreak yields some direct return during the year.

THE CONTROL OF WAVE EROSION

Much of the control of wave erosion is a public problem and involves expensive engineering structures. In other places, farm land is being eaten away by the waves. The value of farm land, however, usually does not warrant the expenditures that can be made to protect public property.

If wave action is not too strong, ordinary legumes such as some of the clovers and leguminous trees and shrubs may be planted or seeded along with nonleguminous ones. Success with such plants is more likely on shores of fresh than of salt waters. Engineering structures are usually too costly for use by the individual owner of farm lands.

Questions

1. What are some of the more recent developments in the control of soil erosion in the United States?

2. Outline the history of the U.S. Soil Conservation Service and its work.

3. Show the relationship between the maintenance of a high level of productivity and protection of the soil against erosion.

4. Discuss the influence of individual crops and their rotation on the control of soil erosion.

5. What are the advantages of contour tillage and seeding of crops?

6. Discuss the advantages and disadvantages of contour strip cropping.

7. What determines desirable widths of strips for a system of contour strip cropping?

8. Give a suitable arrangement of the crops of a 4-year rotation for strip cropping in your section.

9. What benefits may be expected from contour furrows, diversion ditches, and terraces?

10. Outline a program for the control of gullies.

11. Indicate the relationship of agriculture to the silting of reservoirs and the alleviation of floods.

12. Outline a program for the control of wind erosion in the drier areas; of blowing of sand and peat in humid areas.

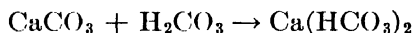
CHAPTER X

SOIL ACIDITY AND ITS CONTROL BY LIMING

Acidity may be defined as a condition in which the concentration of hydrogen ions is greater than that of hydroxyl ions. Neutrality is the point at which the concentration of H^+ ions exactly balances that of the OH^- ions, a condition found in pure water. Alkalinity is the state in which the concentration of OH^- ions is greater than that of the H^+ ions. In the soil more or less soluble mineral matter, decaying plant residues, colloidal clay, and organic matter are in constant contact with the soil solution, all in an ever-changing state. There is produced, as a result, a condition of extreme complexity.

GENERAL CONSIDERATIONS OF SOIL ACIDITY

The Cause of Soil Acidity.- Soils and soil materials originally varied greatly in their content of basic materials. These are gradually lost in the form of bicarbonates or other salts as a result of the reaction of carbonic or other acids with them. The simple reaction between carbonic acid and calcium carbonate may be cited as representative.

$$CaCO_3 + H_2CO_3 \rightarrow Ca(HCO_3)_2$$

Calcium carbonate, $CaCO_3$, itself is relatively insoluble in pure water; the bicarbonate, $Ca(HCO_3)_2$, in contrast, is readily soluble in water and as such is easily lost from the soil in drainage. And this is the manner in which basic materials may pass from the soil leaving it deficient in them and, at length, acid.

Losses of Lime from Soils.—Dunkirk and Volusia soils in the lysimeters at Cornell lost the equivalent of 725 pounds of calcium and magnesium carbonates an acre a year when growing a rotation of crops. The Dunkirk was a 10-, and the Volusia a 15-year average (Table 18, page 103). From uncropped Dunkirk soil, the loss was equivalent to 1,220 pounds of calcium and magnesium carbonates. The outstanding fact is the very high loss

of calcium and magnesium. The reduction by cropping (Dunkirk silty clay loam) from 1,220 to 725 pounds of carbonates an acre a year is notable and constitutes a strong argument for cropping as compared with fallowing humid-region soils.

According to Table 19 (page 104), the average use of calcium by crops is small. By far the larger part of the calcium and magnesium in, or applied to, soils is lost by leaching and is not used by crops.

The Nature of Soil Acidity.—Soil acidity has been regarded as being of two kinds. These are *active* and *reserve*, or *potential*, acidity.

Active Acidity.—Active acidity represents the extent of excess in concentration of H ions over that of the OH ions in the soil

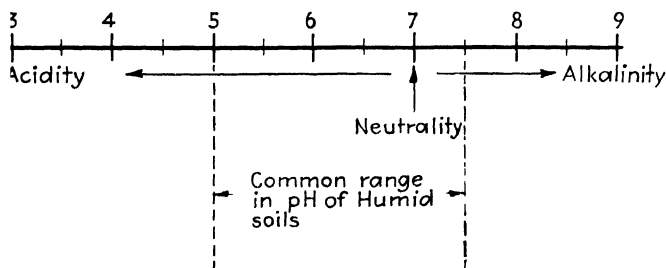



FIG. 111.—A section of the pH scale. Here is represented the part of the pH scale that has a bearing on the pH of ordinary humid soils. The more common ordinary humid soils, it may be noted, fall within a relatively narrow range, of from somewhat below pH 5 to pH 7.5 or 8.

solution. This excess may cause a high degree or intensity of acidity and yet not require the addition of much basic material for its complete neutralization.

Active soil acidity is expressed in pH units, in which 7 represents neutrality, or perfect balance between H^+-ion and OH^--ion concentrations (Fig. 111). The pH readings 6.0, 5.0, 4.0, 3.0 represent increasing acidity, respectively. At pH 5.0, the acidity is 10 times as great as at 6.0; at 4.0, 100 times; and at 3.0, 1,000 times as great as at 6.0. Alkalinity is represented by numerals that are larger than 7.0, such as 7.5 and 8.0. These relationships, it should be noted, are not arithmetic but geometric. That the numerals used to represent the concentration of H^+ ions grow smaller with increasing acidity is at first confusing.

Ranges in pH of below 5.0 to a little above 7.0 are found rather commonly in humid soils, and readings below 3.0 have been

reported as well as some above 8.5. Normally, the extreme range in soils of humid regions, however, is between a little under 4.0 and somewhat above 8.0. Terms such as *slight*, *moderate*, or *high* acidity are of real service in describing soils and may be correlated with definite pH readings for normal mineral soils as follows:

Strong alkalinity	Above 7.5	Moderate acidity	6.0–5.5
Slight alkalinity	7–7.5	Moderate to high acidity	5.5–5.0
Neutrality	7.0	High acidity	5.0–4.5
Slight acidity	7.0–6.0	Very high acidity	Below 4.5

Reserve, or Potential, Acidity.—The reserve, or potential, acidity of soils represents the H ions held in the colloidal matter of the soil. These ions are not so free to move about as are those in the soil solution, but they are in equilibrium with them. The importance of the reserve acidity is this. If lime is added to a soil, its active acidity is quickly neutralized. After this has occurred, H ions come out of the colloidal complex and in time give the soil moisture an acid reaction again. This supplying of H ions to the soil solution explains the extreme importance of the reserve acidity.

It is the reserve acidity with the correction of which the farmer is concerned. He applies limestone to the extent of 1 to 2 tons an acre or more (varying with the fineness of grinding) in order to neutralize the active acidity as H ions come into solution out of their colloidal hiding place. The amount of active acidity in heavy soils is negligible in comparison with that of the reserve acidity. A fairly definite relationship exists between these two types of soil acidity.

The Determination of Acidity of Soils.—Active acidity is determined in pH units. Precise determinations are made with the potentiometer, using the glass electrode. The sample of soil to be tested is shaken with a small quantity of water and allowed to stand in contact with the electrodes until equilibrium is established. The electrical potential readings are then made, and the pH of the soil is calculated.

In another method of determination, advantage is taken of the fact that various indicators have different colors or shades of color that correspond to different pH values. For relatively accurate colorimetric readings, a group of indicators is used.

Each covers a definite part of the pH scale with some overlapping. Similarly, for approximate pH readings a mixture of indicators has been used with satisfactory results. Determinations made in the laboratory with the glass electrode, however, are most accurate. It should be appreciated that the pH of a soil is not a constant value but varies somewhat throughout the growing season.

Effects of Soil Acidity on Availability of Phosphorus.—Phosphorus is most readily available to plants in the zone of slight acidity and becomes less readily available with increasing concentration of H ions. In the zone of high acidity, soluble phosphorus combines with compounds of aluminum and iron, forming highly insoluble aluminum and iron phosphates. In these compounds, phosphorus is only very slightly available to plants.

On the alkaline side, phosphorus combines with calcium, forming tricalcium phosphate. Though not readily available to crops, phosphorus in this form is much more so than in aluminum and iron compounds.

Effects of Soil Acidity on Plants.—In moderate concentrations, H ions do not appear to be detrimental to many plants. Rather it is the conditions in the soil, brought about in the presence of acidity, that are detrimental to plants (see Fig. 111).

Aluminum, iron, and manganese are more soluble at moderate to high acidities than near neutrality. Soluble aluminum compounds and sometimes iron compounds are toxic to plants. Toxic materials that are soluble at the higher H-ion concentrations, rather than the H-ion concentration itself, appear to be a direct cause of the damage to plants that has been attributed to soil acidity.

In the following tabulation are given some representative crops in each of three groups that respond differently to varying degrees of acidity. Those named near the top of each column may be regarded in general as being more sensitive to high acidity than those appearing lower in the lists.

It should be borne in mind, however, that, although an optimum pH for any plant may be determined for a given set of conditions, many plants are capable of good growth throughout a moderately wide range of acidity. This is particularly true if mineral nutrients and organic matter are present in relative abundance.

RELATIVE RESPONSE OF PLANTS TO VARYING DEGREES OF SOIL ACIDITY

Group 1 requires high active calcium content and only slight if any acidity	Group 2 responds satisfactorily to conditions of moderate to high acidity and a moderate content of calcium	Group 3* requires very high acidity and low active calcium content
Alfalfa	Barley	Raspberries
Sweet clover	Bluegrass	Strawberries
Red clover	Beans (garden)	Blueberries
Onions	Sweet corn	Cranberries
Beets	Carrot	Holly
Celery	Soybeans	Rhododendron
Spinach	Alsike clover	Azalea
Lettuce	Corn	Laurel
Cauliflower	Oats	
Cabbage	Wheat	
Eggplant	Orchard grass	
Muskmelon	Timothy	
Chard	Potatoes	
	White clover	
	Lespedeza	
	Tomatoes	
	Millet	
	Turnips	
	Squash	
	Cowpeas	
	Cucumber	
	Buckwheat	
	Vetch	
	Watermelon	
	Redtop	
	Bent grass	
	Poverty grass	

* Little effort was made to differentiate as to active acidity requirements within group 3.
Adapted from Hartwell and associates, Rhode Island Agricultural Experiment Station.

THE CONTROL OF SOIL ACIDITY BY LIMING

Any base-forming material might be used to reduce the H-ion concentration of soils. Calcium and magnesium compounds because of their abundance and ease of accessibility in many areas are generally used for the purpose of controlling soil acidity.

Kinds of Lime in Use.—The term *lime*, although admittedly not entirely correct, is used for the materials applied to soils for

correcting acidity, regardless of their chemical composition. Carbonates, burned lime, hydrated lime, blast-furnace slag, and a few other by-product materials are used on the soil.

Carbonate Forms of Lime.—Limestone, $CaCO_3$, is widely distributed and occurs in large easily workable deposits (Fig. 112). Some limestones are nearly pure calcium carbonate. Others contain small percentages up to about 45 per cent of magnesium carbonate, $MgCO_3$, along with calcium carbonate, a mixture that is called "dolomite." The terms *dolomitic* and *high magnesium*

FIG 112 Limestone quarry in New York Here is shown a medium-sized limestone quarry On the ledge are the well drills that make the holes for the dynamite, the charges of which shatter the rock The train is returning for a load of stone, the steam shovel being in position for loading the end car The stone is taken to the grinding works where it is crushed, ground, and screened, ready to go to the farmer for spreading on the land

are applied to limestones that contain rather large percentages of magnesium carbonate, whereas *high calcium* is the term applied to limestones that contain little magnesium. Limestones contain as low as 60 per cent to a total of nearly 100 per cent of calcium and magnesium carbonates. A stone containing less than 80 per cent is of poor quality, and stones that contain 90 per cent are good; but those which have in excess of 95 per cent of total calcium and magnesium carbonates are preferred.

Limestones are ground to varying degrees of fineness for use on the soil. An enormous amount of experimental work has been done to determine the best fineness of grinding Somewhat less

stress is placed on fineness than a decade ago, but more now than 30 years ago. A limestone of good analysis 50 per cent of which passes through a screen of 100 meshes to the inch,[1] 90 per cent through a 20-mesh screen, and all through a 10-mesh screen, gives satisfactory results in normal quantities to the acre. This degree of fineness is commonly used in the Northeastern states. Coarser stones are used with good results, but they are applied in such amounts to the acre as supply suitable quantities of the finer material. Screenings and 10-mesh stones as used in the Midwest

FIG. 113. – Marl. The marl here is overlaid by about three feet of peat. This marl is of good quality but getting it out for use on the soil is difficult because of the water. The marl extends some distance below the surface of the brown colored water.

carry less than 30 to about 50 per cent of 50-mesh material. It is the fine material that is most effective during the first year or two after limestone is mixed with the soil. The kind or fineness of liming material to use depends on prices. That which ensures satisfactory growth of legumes for the least expenditure per acre is recommended.

Marl is unconsolidated limestone. It occurs in bogs and swamps, the calcium and magnesium having been leached from calcium- and magnesium-bearing materials, usually located near by (Fig. 113). Owing to its location, more or less in-washed silt and clay are found in marl. The great difficulty usually is

[1] U.S. Bureau of Standards sizes.

getting the marl out of the water in which it normally occurs. Pound for pound of carbonates of comparable fineness, marl may be expected to give results as good as or better than limestone. Except for use on land immediately adjacent to the deposit, marl should contain in excess of 75 per cent of calcium and magnesium carbonates. Many samples have 80 or 90 per cent or more of total carbonates.

Oyster shells are a suitable liming material, either burned or ground to proper fineness. In their natural condition, they contain 90 to 95 per cent of calcium carbonate.

Burned Lime.—Limestone is burned for building purposes and for use on the soil. *Burned lime, lump lime,* and *quicklime* all refer to calcium oxide. Some years ago, burning limestone for soil use was a common practice; it is still done to some extent. In burning, carbon dioxide is driven out of the stone as a gas.

Calcium carbonate		Carbon dioxide		Calcium oxide
$CaCO_3$	$-$	CO_2	$=$	CaO
100		44		56

The molecular weight of calcium carbonate is 100

$$(Ca = 40) + (C = 12) + 3(O = 16).$$

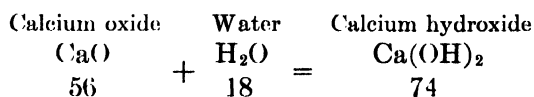
On burning, 100 pounds of pure calcium carbonate lose 44 pounds of carbon dioxide, and 56 pounds of calcium oxide result. Since no calcium is lost in burning, this amount of quicklime contains all the calcium that was in the original stone. In other words, calcium constitutes 71.4 per cent of the pure oxide, whereas it constitutes only 40 per cent of the carbonate.

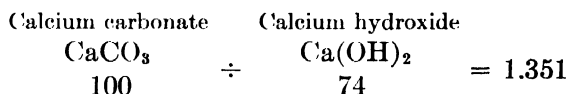
Any form of lime produces calcium ions in the soil. And since it is the calcium ions that displace H ions in the correction of acidity, 56 pounds of calcium oxide and 100 pounds of calcium carbonate have the same total effect in neutralizing soil acidity.

Calcium carbonate		Calcium oxide	
$CaCO_3$	$\div$	CaO	$= 1.784$
100		56	

In other words, 1 pound of the oxide supplies the same amount of calcium as 1.784 pounds of calcium carbonate.

Hydrated Lime.—Hydrated lime, hydrate, agricultural hydrate, and water-slaked lime are the commonly used names for calcium hydroxide, $Ca(OH)_2$. It is formed by the direct addition of water to calcium oxide.

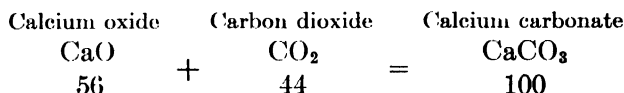
Calcium oxide		Water		Calcium hydroxide
CaO	+	H_2O	=	$Ca(OH)_2$
56		18		74

Calcium hydroxide has a molecular weight of 74. Pound for pound, therefore, it is less effective in replacing H ions than is calcium oxide, but it is more effective than is calcium carbonate.

Calcium carbonate		Calcium hydroxide	
$CaCO_3$	÷	$Ca(OH)_2$	= 1.351
100		74	

One pound of hydrate, therefore, is equivalent to 1.351 pounds of the carbonate; conversely, 1 pound of pure calcium carbonate does the same work as 0.74 pound of hydrate. In the trade, however, the composition of the hydrate is often stated as per cent of calcium oxide, CaO. On that basis, the relationship with the carbonate is the same as for calcium oxide in burned lime.

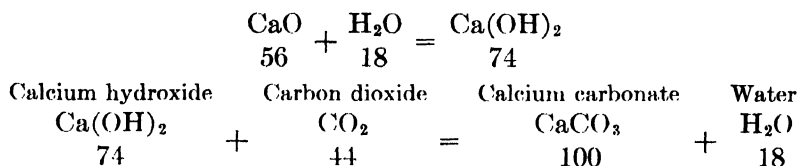
Since limestones carry impurities, the relationships stated apply only to the calcium compounds and not to commercial limestones and burned limes and agricultural hydrated limes as such.

Commercial hydrate is usually handled in paper bags. Lime that is burned in home or local kilns may be slaked or hydrated at the kiln or on the farm and is handled without bagging. Hydrating is sometimes done in small piles in the field and the hydrate spread with a shovel directly from the piles.

Air-slaked lime forms when either calcium oxide or hydroxide takes up carbon dioxide and returns to the original carbonate form. Thus,

Calcium oxide		Carbon dioxide		Calcium carbonate
CaO	+	CO_2	=	$CaCO_3$
56		44		100

This precise reaction may not take place directly; yet the illustration may be helpful. The following probably occurs in the soil:

$$\underset{56}{CaO} + \underset{18}{H_2O} = \underset{74}{Ca(OH)_2}$$

$$\underset{74}{\overset{\text{Calcium hydroxide}}{Ca(OH)_2}} + \underset{44}{\overset{\text{Carbon dioxide}}{CO_2}} = \underset{100}{\overset{\text{Calcium carbonate}}{CaCO_3}} + \underset{18}{\overset{\text{Water}}{H_2O}}$$

Calcium carbonate, the original chemical form, is the result of air-slacking in either case.

Blast-furnace Slag.—Blast-furnace slag is a by-product of the manufacture of pig iron from the ore and limestone. It contains much calcium silicate and some calcium carbonate and iron. Owing to its glassy nature, fine grinding is essential. Recent work reported by White, Holben, and Jeffries[1] in Pennsylvania indicates a high value for purposes of correcting soil acidity.

Ashes.—Fresh hardwood ashes, ton for ton, contain calcium approximately equivalent to that in a high-grade limestone and about 4 per cent of potash and 1.5 to 2 per cent of phosphoric acid, both of which are of value in the soil.

Gypsum and Salt.—Gypsum and common salt have little or no value for correcting acidity. If some of the calcium or sodium is used or leached away, an actual acidifying effect may be produced.

Comparative Effects of Different Forms of Lime.—The calcium and the magnesium are the active agents in liming materials. The effectiveness of limes, therefore, is closely correlated with the total quantity of these elements present. This statement is, of course, based on the assumption that the carbonate forms are of suitable fineness. Some allowance may be made for the more rapid action in the soil by burned and hydrated, as compared with the carbonate, forms. Growers in New York generally apply hydrated lime for cauliflower and for cabbage if serious danger of clubroot, or "finger-and-toe" disease, exists. The pH can be raised or the H-ion concentration reduced toward neutrality more rapidly with the quicker acting forms than with limestone.

For making a comparison of values of different forms of liming materials, the conversion factors given in Table 31 may be used.

[1] White, J. W., F. J. Holben, and C. D. Jeffries, The Agricultural Value of Specially Prepared Blast Furnace Slag, *Pennsylvania Agr. Exp. Sta., Bull.* 341, 1937.

The factors in Table 31 are based on theoretical chemical equivalents. Little doubt exists but that magnesium compounds in burned and hydrated limes are effective to the full extent of their chemical equivalents. Because of its slower action in the soil, some doubt exists whether magnesium carbonate is worth any more, pound for pound, than calcium carbonate. A mass of experimental work comparing the two forms fails to establish any marked superiority of magnesium over calcium carbonate in the

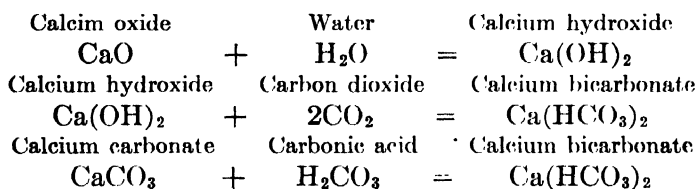
TABLE 31.—CONVERSION FACTORS FOR LIMING MATERIALS

Given, per cent as	To find, per cent as	Multiply by
Calcium oxide, CaO	Calcium carbonate, $CaCO_3$	1.784
Calcium carbonate, $CaCO_3$	Calcium oxide, CaO	0.560
Calcium hydroxide, $Ca(OH)_2$	Calcium oxide, CaO	0.757
Magnesium oxide, MgO	Magnesium carbonate, $MgCO_3$	2.091
Magnesium carbonate, $MgCO_3$	Magnesium oxide, MgO	0.478
Magnesium hydroxide, $Mg(OH)_2$	Magnesium oxide, MgO	0.691
Magnesium carbonate, $MgCO_3$	Calcium oxide, CaO equivalent	0.664
Magnesium hydroxide, $Mg(OH)_2$	Calcium oxide, CaO equivalent	0.960
Magnesium oxide, MgO	Calcium oxide, CaO equivalent	1.390
Magnesium carbonate, $MgCO_3$	Calcium carbonate, $CaCO_3$ equivalent	1.186

production of crops on acid soils. It appears, therefore, that the sum of the calcium and magnesium or the total carbonates is as suitable a method for evaluating limestones for use on the soil as calcium carbonate equivalent. This figure includes the calculated theoretical equivalent of magnesium.

Magnesium is an essential plant-nutrient element. For this reason, if a shortage or even a remote danger of shortage of magnesium exists, the use of limestone carrying some magnesium is justified. Alternating applications of high-calcium with high-magnesium limestones may be advisable. For humid areas, there is no recognized objection to the use of dolomitic liming materials.

Action of Lime in the Soil.—Lime in any of the regularly used forms reacts rather quickly with moist, acid soils. The three forms, oxide, hydroxide, and carbonate, react somewhat differently; but the final product is the same.

Calcim oxide		Water		Calcium hydroxide
CaO	+	H_2O	=	$Ca(OH)_2$
Calcium hydroxide		Carbon dioxide		Calcium bicarbonate
$Ca(OH)_2$	+	$2CO_2$	=	$Ca(HCO_3)_2$
Calcium carbonate		Carbonic acid		Calcium bicarbonate
$CaCO_3$	+	H_2CO_3	=	$Ca(HCO_3)_2$

It should, of course, be appreciated that in addition to these conventional reactions numerous complex reactions with the materials held in the colloidal matter occur simultaneously.

Correction of Acidity.—As already stated, acidity is the result of the accumulation of an excess of H ions over the OH ions. The bulk of the H ions are held in close association with the colloidal matter. When a form of lime is added to a moist soil, part of the calcium becomes ionized and is represented as Ca^{++}. Calcium, magnesium, sodium, potassium, and ammonium ions or cations have the power of exchanging places with each other or with hydrogen in a colloidal complex such as that in the soil. This action is commonly referred to under the general term of *ionic*, or *base, exchange*.

After an application of lime to moist soil, the soil solution becomes charged with Ca^{++} ions. Being active, they soon change places with H^+ ions in the colloidal complex. The H^+ ions are released into the soil solution where they unite with OH^- ions and form water. In time, many of the H^+ ions are replaced by the Ca^{++} ions; and the colloidal clay, then being dominated by calcium, is no longer acid. In other words, the acidity of the soil has been neutralized or corrected for the time being. Because of the continued generation of H^+ ions which displace Ca^{++} ions in the colloidal material, the H^+ ions eventually make the soil acid again. Moreover, carbon dioxide aids in bringing about the formation of calcium bicarbonate by drawing Ca^{++} from the colloidal material; and the bicarbonate in turn may be lost by leaching. After a sufficient amount of calcium has been removed from the soil, it is back in its previous acid condition and another

application of liming material is required for growing the more sensitive or lime-loving legumes.

FIG. 114.—Effect of liming on yield of clover. On the left is the hay from the limed plot; on the right from unlimed soil. Not only does liming acid soils greatly increase the yield of clover but it markedly improves the quality of the hay as well. Moreover, liming increases the growth of grass or other nonlegume crop that follows clover. (*Courtesy of Cornell Univ. Agr. Ext. Service.*)

FIG. 115.—Effect of liming on growth of corn on strongly acid soil. The corn on the left is growing on limed land, that on the right on unlimed soil. Obviously the total yield is markedly increased by liming. (*Courtesy of A. W. Blair.*)

Effect of Liming on Crop Yields.— Soil conditions vary greatly and the crops have different requirements with respect to lime. No specific statement can be made, therefore, as to the increase

in yield that may be expected from a given application of lime. The tabulation Relative Response of Plants to Conditions That Accompany Varying Degrees of Soil Acidity (page 231) is of interest in this connection. From this tabulation, it may be expected that liming may help some plants but injure others. Some indications, however, can be given with respect to effects of liming for specific crops (Figs. 114, 115, and 116).

FIG. 116.—Above, effect of acidity on growth of beets. Yield at pH 6.5, left, 11,970 pounds; at pH 5.0, right, 2,928 pounds per acre. Below, yield of lettuce at pH 6.5, left, 5,610 pounds; at pH 5.0, right, 1,832 pounds to the acre. (*Courtesy of Virginia Truck Exp. Sta.*)

Data from the Ohio Experiment Station are given in Table 32. Specific attention is called to the effect of liming as shown in column 4 of that table. The yields of oats and wheat were doubled, of corn more than trebled, of clover almost quadrupled; the yield of timothy was almost three times that produced without liming. Fertilization in addition to liming gave further marked increases in yield, as shown in the final column of Table 32.

Timothy ordinarily is not sensitive to moderately strong acidity. Without fertilization, liming increased the yield of timothy nearly 1 ton; liming and fertilization together increased it almost 1½ tons to the acre. Much of this increase is to be

TABLE 32.—EFFECTS ON YIELDS OF LIME AND FERTILIZER APPLIED SEPARATELY AND TOGETHER ON THE SAME ACID SOIL, 1917–1931*

Crop	No fertilizer	Lime		Fertilizer†		Lime and fertilizer†		
	Yield	Yield	Gain over no lime	Yield	Gain over no fertilizer	Yield	Gain over no treatment	Gain over lime and fertilizer applied separately
Corn, bushels.....	7.7	24.9	17.2	23.6	15.9	45.8	38.1	+5.0
Oats, bushels.....	19.5	38.7	19.2	36.0	16.5	49.0	29.5	−6.2
Wheat, bushels...	4.9	14.5	9.6	17.7	12.8	27.9	23.0	+0.6
Clover, pounds...	546	2,045	1,499	1,288	742	3,405	2,859	+618
Timothy, pounds.	1,018	2,955	1,937	1,496	478	3,865	2,847	+432

* Handbook of Experiments in Agronomy, *Ohio Agr. Exp. Sta., Sp. Cir.* 53, p. 59, 1938. Experiment begun in 1894. Lime applied regularly since 1903 and 1904.

† "Without fertilizer, crops grown on unlimed soil have been worth only 36 per cent as much as those grown on limed land. With fertilizer, they have been worth 54 per cent as much. Lime without fertilizer has produced larger yields of all crops except wheat than fertilizer without lime."

credited to the effect of the nitrogen fixed and left in the soil by the clover. The liming, however, enabled the clover to make good growth and to fix the nitrogen. Consequently, the increase in the production of the timothy is, in fact, the result of liming. The effects of liming in Ohio are representative of the increases in yield for these crops that may be expected on soils that are really deficient in lime.

Form of Lime to Use.—Many considerations enter into a decision as to the form of lime to use. Among them are: (1) the cost per acre, hauled to the farm and spread on the land; (2) the crop to be grown; (3) the relative need for quick correction of acidity; (4) the expected profit from the crop grown; (5) the indirect effects of the lime. For feed crops, the form of lime (of suitable fineness) that gives the largest quantity of actual calcium spread on the land per dollar invested is often most economical. As previously stated, burned and hydrated limes correct acidity more quickly than do limestones. If speed of

action is essential and if the crop will pay for them, the more quickly acting forms may well be considered. For various vegetable crops, speed of reaction rather than relative cost may determine the form to use. The heavy application of liming materials often made for cauliflower makes soil conditions favorable for clovers, alfalfa, and grains over a period of several years. And if the legumes are grown, they may (as shown in Table 32) materially increase the yields of nonleguminous crops grown after them.

Quantity of Lime Required.—After selecting the most economical form of lime for use, the quantity to put on to the acre must be decided upon. The best amount to apply depends in part on factors other than soil acidity and the crop to be grown. An estimate based on all the information available with respect to fertilization, manuring, and liming and the yields of the crops grown during the years immediately preceding is always helpful. If good inoculated clover seed was used and if rainfall was ample but the crop failed, liming at the rate of 1 ton or more to the acre of suitable, finely-ground limestone or its equivalent in other forms is in all probability needed. More of coarser stones is required. Testing the soil by means of one of the better lime-requirement tests often yields additional information of real value for estimating the amount of lime to use to the acre.

Lime-requirement Tests.—During recent years, many tests have been devised and used for a time. These have been intended to improve one's estimate of the need of lime for specific crops. Methods depending on base exchange were tried. Lime-requirement readings were high, and yet the methods were helpful. More recently the determination of the H-ion concentration has been widely used (page 229). The potassium thiocyanate test by Comber[1] also is commonly used. It is based on the fact that iron is soluble in acid soils, and the test detects soluble iron. The intensity of color developed varies with the acidity. The assumption is that soluble iron in the soil is accompanied by soluble, and therefore toxic, aluminum. This test is used for estimating lime requirements for clover and alfalfa in particular.

[1] COMBER, N. M., A Qualitative Test for Sour Soils, *Jour. Agr. Sci.*, Vol. 10, pp. 420–424, 1920.

———, A Modified Test for Sour Soils. *Jour. Agr. Sci.*, Vol. 12, pp. 370–371, 1922.

The use of soils of known lime requirement, or of *standard soils,*[1] for comparisons of color rather than color charts alone is believed to lead to an improvement in the lime-requirement estimates made under many conditions.

Liming for Special Crops.—Some special plants require a fairly narrow range of pH, and some as already indicated need high acidity. Soils vary in the quantity of lime required to bring about a given change in pH. Light sandy soils require relatively little lime to change their pH, for they contain little clay or organic matter that resist such change. This resistance to change is called *buffering action*, and the colloidal material is called a *buffer*. Heavy soils, on the other hand, are well buffered and strongly resist change in pH. Much lime, therefore, is required to change the pH of clays. Sprague determined the quantities of hydrated lime (from 1⅓ to 1½ times as much of finely ground limestone) required to change the pH of a wide range of soil textures. His data are given in Table 33.

TABLE 33.—POUNDS OF HYDRATED LIME REQUIRED TO REDUCE SOIL ACIDITY TO THE DESIRED EXTENT*

Soil acidity expressed in pH values	Lime, pounds per 1,000 sq. ft.			
	Light sandy soils	Medium sandy loam soils	Loam and silt loam soils	Clay loam soils
pH 4.0	60†	80	115	145
pH 4.5	55	75	105	135
pH 5.0	45	60	85	100
pH 5.5	35	45	65	80
pH 6.0‡	None	None	None	None

* SPRAGUE, H. B., Liming Lawn Soils, *New Jersey Agr. Exp. Sta., Circ.* 362, p. 4, 1936.

† Multiplying these figures by 43 gives approximately the corresponding application on the basis of an acre.

‡ Acidity at pH 6.0 is so slight as not to be objectionable.

A little time must be allowed for lime to bring about the desired changes in the pH of the soil, especially for the forms whose action is slow.

[1] GUSTAFSON, A. F., The Use of Standard Soils with the Potassium Thiocyanate Test for Estimating Lime-requirement of Soils, *Jour. Amer. Soc. Agron.*, Vol. 16, pp. 772–776, 1924.

Overliming Possible.—Considerable care is required to avoid damaging certain plants through overliming. This danger is, of course, greater for acid-soil plants and others that thrive in, or at least tolerate, relatively high acidity. For lime-loving plants, in contrast, danger of overliming is not great.

Additions of considerable lime to soils of fairly high acidity suddenly change the relations between the H and OH ions in the soil. Soil organisms tend to adjust themselves to existing conditions, including the pH. Sudden changes, therefore, require quick adjustments. Moreover, the solubility of iron, aluminum, and manganese tends to be relatively high in acid soils. Excessive liming renders all these and other elements less soluble so that plants temporarily may not obtain an adequate supply of them, and retardation or stoppage of growth and reduced yields may result.

Some danger attends the making at one time of single applications to acid soils of 3 to 5 tons or more of finely ground limestone to the acre. These quantities of coarsely ground limestone, however, are unlikely to cause trouble. If the stone contains a considerable quantity of fine material, the reaction may be brought to pH 7.0 or higher. High alkalinity may render iron and the trace elements insoluble and deprive plants of them. Reduced yields of acid-tolerant crops may follow. It is probably best to hold the application of lime to such amounts as will produce good growth of the more sensitive crops. Thrifty legumes in the rotation are of course essential.

"Light" Liming.—"Light" applications in the row of a few hundred pounds of liming material to the acre have given surprisingly good growth of certain legumes.[1] The lime is applied with the fertilizer attachment of the grain drill in essentially direct contact with the seed. Here it sets up a zone of alkalinity that appears to produce satisfactory results with sweet clover, in particular.

Time of Applying Lime.—Limestone corrects acidity rather slowly. The finer ground stones, however, act more rapidly than the coarser ones. Burned and hydrated limes act more quickly than do the carbonate forms. In fact, in moist soils, burned and hydrated limes may do their full work in a few days.

[1] Albrecht, W. A., and E. M. Poirot, Fractional Neutralization of Soil Acidity for the Establishment of Clover, *Jour. Amer. Soc. Agron.*, Vol. 22, pp. 649–657, 1930. (Brief bibliography included.)

Because the effect of lime is distinctly the result of contact between the lime and the soil, thorough mixing with the soil is essential for good results. And for this reason a finely ground limestone gives quicker effects because of the large surface in contact with the soil. Moreover, the fine limestone consists of many particles which if well mixed with the soil constitute many centers of alkalinity. This condition is desirable because lime does not move readily or quickly over considerable distances in the soil. Even downward movement through the soil in the field is very slow.

Because the action of limestone is slow, it should be applied a considerable time in advance of seeding a sensitive crop such as alfalfa or even red clover. If the lime requirement for these crops is 1½ or 2 tons or more of finely ground limestone to the acre, one-half of it may well go on for a cultivated crop, and the remainder the same fall after plowing or after plowing the following spring. And the spring application ought to be mixed with the soil as long as possible before seeding alfalfa in order that the acidity may be reduced as much as possible before the seed germinates. Application well in advance of alfalfa in order to reduce the acidity is desirable for this crop.

A similar application, a year ahead, to a field to be planted to cauliflower might reduce the need for the usual extremely heavy application of hydrated lime. Some financial saving would probably result.

Some soils need 1 ton of finely ground and more of a coarser limestone to the acre for red clover when seeded in a 3- or 4-year rotation. On such soils, application in the spring ahead of seedbed preparation for the nurse-crop grain usually gives good results. In a rotation of corn, oats, clover, and timothy, it is satisfactory for red clover if lime is applied before corn is planted, particularly after a few years of consistent liming.

Alfalfa and red clover have been treated as representative of the legumes that have high and medium lime requirements, respectively. Lespedeza, white clover, cowpeas, soybeans, and crotalaria are less exacting with respect to lime and the time of its application.

Methods of Applying Lime.—In the earlier days, lime was spread by hand out of the pile where it was slaked in the field. Lump lime, if home slaked and then screened to remove any unburned cores, may be spread with an ordinary lime sower.

Owing to the dusty nature of all the forms of lime, applying them with a lime sower is the ideal method (Figs. 117 and 118). Not only is hand spreading hard work, but a uniform spread takes much time. And hand spreading seldom gives as good results as does distributing with a good lime sower.

In many parts of the country, the cost per acre of liming materials spread on the soil is rather high—in fact, high enough so that it limits the tonnage to an amount far below that which could be used to economic advantage. The hauling of limestone from

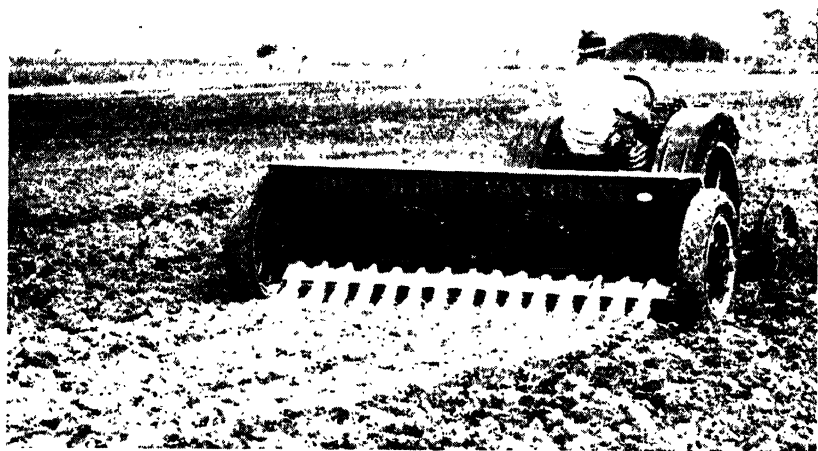



FIG. 117.—The drill type of lime spreader. Lime may be spread with a highly satisfactory degree of uniformity with a machine of this type. (*Courtesy of John Deere, Moline, Ill.*)

the grinding plant directly to the field in large trucks is economical for varying distances. This is particularly true if soil conditions are such that the spreader can be attached to the rear end of the truck and the limestone thus spread with a minimum of labor. Meadow stubble, being firm, is a suitable place for the spreading of limestone in this manner. It may be done at any time after the hay is harvested until the soil freezes or even until heavy snowfall. The lime is plowed down for a cultivated crop and in a measure back up again for the nurse crop and thus becomes thoroughly mixed with the soil. The convenience and the saving in labor costs from spreading in this manner will

undoubtedly more than pay the interest on the lime for the time before the cash returns from its use are obtained. Moreover, the lime benefits, to some extent, the crops that precede clover and this offsets in large measure the loss by leaching during the time that has elasped since it was applied.

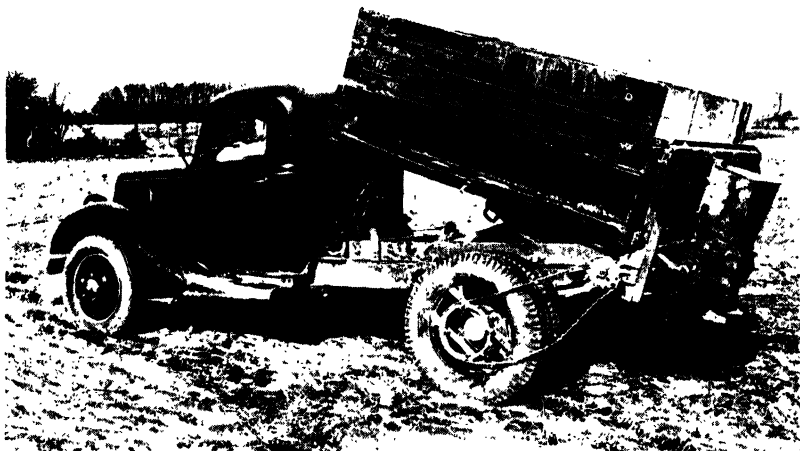



FIG. 118.—The endgate type of spreader. Limestone is not so uniformly distributed with this as with the drill type of spreader. Over a period of years, however, this method of spreading should prove satisfactory. A distinct advantage of the endgate type of machine is that it can spread wet liming materials satisfactorily. (*Courtesy of G. L. F. Exchange.*)

Liming in Relation to Plant Diseases and Deficiency Disorders. Some plant-disease organisms are sensitive to acidity, others to alkalinity. The organisms that cause potato scab function over a wide range in pH, as shown in Table 34 from results obtained by Smith in New York.

This experimental work was done on Dunkirk silty clay loam. The reactions were produced by applying sulphur and by liming. The crop received 1,000 or 1,200 pounds of 5-10-5 fertilizer annually. It may be noted that the percentage of scabby tubers was high, between pH 5.6 and 6.15, without addition of green manures and that 61 per cent of the potatoes were scabby, between pH 6.50 and 7.13. Though a drop in the percentage occurred, yet 27 per cent of the tubers were scabby even at pH 7.9. This was the eighth successive crop of potatoes grown on this soil with no

TABLE 34.—THE EFFECT OF SOIL REACTION AND OF GREEN MANURING ON YIELD OF SMOOTH RURAL POTATOES AND PERCENTAGE OF SCABBY TUBERS ON DUNKIRK SILTY CLAY LOAM* (1939)†

Soil reaction	Potatoes 8 successive years without organic matter added			Potatoes 6 years; corn and rye 1 year, plowed in; then potatoes		
	U.S. No. 1's, bushels per acre	Total yield, bushels per acre	Scabby tubers,‡ per cent	U.S. No. 1's bushels per acre	Total yield, bushels per acre	Scabby tubers,‡ per cent
4.92–5.56	130	167	35	209	249	23
5.60–6.15	128	160	90	178	220	87
6.18–6.49	123	152	80	150	188	71
6.50–7.13	106	139	61	139	179	29
7.37–7.82	91	125	45	142	179	20
7.82–7.91	82	115	27	120	158	19

* SMITH, ORA, Unpublished data, Dept. of Vegetable Crops, Cornell Univ. Agr. Exp. Sta. 1939.

† 1939 was a very dry year.

‡ Not all of the scabby tubers were unsalable. Scab was worse with increasing percentages of scabby tubers.

addition of organic matter. Under these conditions, therefore, high alkalinity did not eliminate scab.

On half of each plot, a heavy crop of corn was grown the seventh year and turned under. Rye was seeded as a winter cover and plowed in for potatoes the following year. The highest percentage of scab occurred at the same pH with as without green manure. It is noteworthy, however, that a marked drop in percentage of scabby tubers occurred at pH 6.5 and decreased slightly with increasing alkalinity. The yield of scab-free U.S. No. 1 potatoes was nearly twice as great following 1 year of green manuring as without additions of organic matter at the pH that gave the highest yield. Moreover, green manuring reduced the proportion of scabby tubers by 16 per cent, as an average of the pH ranges studied. Even though other factors are involved, the effect of green manuring appears to be significant.

The fungus that causes "take-all" in wheat thrives in slightly acid soils. The organism that causes clubroot, or "finger-and-toe," of cabbage, turnips, cauliflower, and Brussels sprouts thrives in and does serious damage to these and related crops on moder-

ately acid soils, but it is controlled by liming to moderate alkalinity. The pH desired for control cannot be obtained quickly, if at all, by using limestone. On badly infected soils, it is advisable to use at least some hydrate or burned lime for the control of the disease of these crops on acid soils.

In some areas, temporary deficiency disorders of crops that result from a lack of available manganese or iron are found on soils whose reaction is well above neutrality as the result of recent heavy liming.

Growing Acid-soil Plants.—Gardeners often desire to grow acid-soil plants on soils whose reaction is not sufficiently acid for them. Treatment to increase acidity is then required. Aluminum and iron sulphate and sulphur may be used for this purpose. Acidifying material acts best if well mixed with the surface soil to a depth of 6 to 9 inches. The quantities of finely powdered sulphur required are given in Table 35.

TABLE 35.—QUANTITIES OF SULPHUR REQUIRED FOR CHANGING THE pH OF SOILS*

Original Acidity of Soil	Sulphur per Sq. Yd.
Moderate acidity (pH 5.5–6.0)..	2 lb.
Slight acidity (pH 6.0–7.0).....	4 lb.
Slight alkalinity (pH 7.0–7.5)...	7 lb.
Strong alkalinity (pH 7.5+)....	Unsuited for acid-soil plants

* Fertilizer Recommendations for New York, *Cornell Ext. Bull.* 281, p. 34, 1939.

About 60 days after the sulphur is mixed with the soil, a test of it should be made. If the pH is still above 5.5, a second application is made. Even with sulphur, a high organic content is desirable for these acid-soil plants. The buffering action of colloidal matter affects the change in pH toward increased as well as toward reduced acidity. The quantities of sulphur needed may, therefore, be somewhat greater than shown in Table 35 for the heavier and higher organic-content soils.

Questions

1. What causes soil acidity?
2. How may soil acidity be determined?
3. What is the relative magnitude of losses of calcium and magnesium from arable soils?
4. Discuss the effects of soil acidity on plants and on the availability of phosphorus.
5. What are the relative merits of the different soil-liming materials?

6. What is the action of lime in the correction of acidity and the effect on yields of certain crops?

7. How may the quantity of lime needed to the acre for red clover be estimated?

8. Discuss "light" liming and possible danger from overliming.

9. How may soils that are moderately well supplied with calcium carbonate be managed for the growing of acid-soil plants?

10. Discuss the relation of liming to plant diseases.

CHAPTER XI

THE MANAGEMENT OF ALKALI SOILS

THE ALKALI SOILS OF ARID AND SEMIARID REGIONS

Where the average rainfall is less than 20 inches, the soils are commonly referred to as being in the *arid* or *semiarid* groups. Some authorities place the soils that occur in areas having less than 10 inches of annual rainfall in the arid group and those where the rainfall is from 10 to 20 inches in the semiarid group. In many of the arid and semiarid areas in the western part of the United States, there are distinct wet and dry seasons. Under these moisture conditions, the soluble salts produced by the weathering of soil minerals are not leached away but accumulate in the form of alkali crusts on the surface of the soil.[1] Since the rainfall is generally low, they move downward into the soil only a short distance during the rainy season and accumulate again on the surface during the next summer.

The accumulation of soluble mineral salts is most commonly found in those areas where poor drainage conditions exist, as in enclosed basins or in places where the land is fairly level and the texture of the surface or subsoil tends toward clay. This does not mean that sandy soils are free of alkali, for the climatic and

[1] Additional information may be found in the following publications:

Breazeale, J. F., A Study of the Toxicity of Salines That Occur in Black Alkali Soils, *Arizona Agr. Exp. Sta., Tech. Bull.* 14, pp. 337–357, 1927.

Burgess, P. S., Alkali Soil: Studies and Methods of Reclamation, *Arizona Agr. Exp. Sta., Bull.* 123, pp. 157–181, 1928.

Stewart, R., and W. Peterson, Origin of Alkali, *Jour. Agr. Research,* Vol. 10, pp. 331–353, 1927.

Thomas, E. E., Reclamation of White Alkali Soils in the Imperial Valley, *California, Agr. Exp. Sta., Bull.* 601, 1926.

Johnston, W. W., and W. L. Powers, A Progress Report of Alkali Land Reclamation Investigations in Eastern Oregon, *Oregon Agr. Exp. Sta., Bull.* 210, 1924.

Scofield, C. S., and Frank B. Headley, Quality of Irrigation Water in Relation to Land Reclamation, *Jour. Agr. Research,* Vol. 21, pp. 265–278, 1921.

drainage conditions may be such that the weathered soil minerals are not removed by percolating waters. Alkali salts frequently accumulate in low-lying areas, owing to the lateral movement of seepage water from higher elevations.

As one studies soils in the drier regions of the world, he is impressed by the frequency with which such terms as "alkali," "alkaline," and "saline" are used to express certain soil characteristics. An *alkali* soil,[1] as used in this discussion, may be defined as one containing any soluble salts in sufficient amounts to cause injury to economic plants, and an *alkaline* soil as one that has an alkaline reaction due to the presence of an excessive amount of alkaline salts, usually sodium carbonate. *Saline* soils are those which contain excessive amounts of the neutral or non-alkaline salts, usually chlorides and sulphates. On the basis of this definition, an alkaline soil has a pH above 7, and a saline one a pH of 7 or less. The separation of alkali soils into alkaline and saline is the common practice in the western part of the United States.

In order to produce good crops of greater variety and to lengthen the growing season, many farmers in the drier areas have resorted to the use of irrigation water. As the water used for irrigation contains more soluble mineral matter than does rain water, it follows that irrigation under such conditions increases the soluble-salt content of the soil unless the water is wisely applied.

Some farmers have used irrigation water in excessive amounts. Hence, the water table has been raised so close to the surface that the upward movement of soil moisture during the warmer season of the year has been increased, thus providing a more favorable condition for alkali concentration in the surface soil. Seepage from irrigation canals has also been responsible in some cases for raising the water table. It should be clear, therefore, that soils under certain environmental conditions will contain alkali and, furthermore, that improper management of irrigated land may accentuate alkali accumulation.

Harmful Alkali Salts.—Carbonate, bicarbonate, chloride, and sulphate of sodium are in general the main compounds present in the soluble salts that designate an alkali soil. Some soil

[1] Report of the American Soil Survey Association, Committee on Terminology, pp. 23–58, 1928.

investigators have stated that the alkaline reaction of certain alkali soils is due to the presence of sodium hydroxide.[1] Compounds of calcium, magnesium, and other elements may be present in larger amounts than the sodium salts but the calcium and magnesium salts seldom cause injury to plant life.

Alkali soils are sometimes designated as "white alkali" or "black alkali" because of the color of the alkali crust formed on the soil during the dry months of the year. The white alkali soils are the neutral or saline soils, and the black alkali soils are more alkaline chemically than the white. The reaction of alkaline soluble salts with the organic matter in a soil produces the dark color that is so characteristic of black alkali. Since other chemicals in soils may cause a similar discoloration, the black crust is not always an indication that black alkali is present. According to Kelley,[2] black alkali always contains a large amount of absorbed sodium whereas white alkali may or may not contain this material.

Effect of Alkali Salts on Plants.—The presence of a large amount of soluble salts in the soil produces an environment that is not favorable for most plant life. The injury produced may be due to the effect of the high concentration of the salts in the soil solution which changes the soil moisture and plant interrelationships. The best environment for most cultivated plants is one where the soil solution is rather dilute. In alkali soils, in contrast, the concentration of the soil solution is high because of the large amounts of soluble salts present. Also, sometimes a corrosive action is noticed on the roots and near the crown of the plant. Black alkali is the most toxic to plants; next in order, usually, are sodium chloride and then sodium sulphate. In irrigated soils, the growing plants are generally stunted and spotted; the leaves may be yellow if much alkali is present.

Tolerance of Plants to Alkali.—The presence of alkali is quite often indicated in virgin soils by the growth of alkali-resistant weeds and grasses, such as the Australian saltbushes, greasewood, alkali-heath, bushy samphire, saltwort, salt grass, Bermuda grass,

[1] BREAZEALE, J. F., and W. T. MCGEORGE, Sodium Hydroxide Rather than Sodium Carbonate the Source of Alkalinity in Black Alkali Soils, *Arizona Agr. Exp. Sta., Tech. Bull.* 13, 1926.

[2] KELLEY, W. P., The Reclamation of Alkali Soils, *California Agr. Exp. Sta., Bull.* 617, 1937.

FIG 119 —Injury to barley Barley sown the previous fall failed to germinate over the greater part of this area which contained a high concentration of black alkali (*Courtesy of W P Kelley*)

FIG 120 —Failure of alfalfa on black alkali soil This area was flooded and drained but not treated with sulphur or any other chemicals The alfalfa was sown Feb 21, 1929 and photographed May 15, 1929 Most of the plants died soon after the date the photograph was taken. (*Courtesy of Edward E Thomas*)

and tussock grass.[1] Generally, grains, such as rye and barley, are fairly tolerant to alkali (Fig. 119). Rice has been grown successfully on white alkali soils, but it should be kept in mind that in the culture of this crop it is the practice to have sufficient water on the soil to cover it to a depth of at least 6 inches until the plant reaches maturity, when the fields are drained. Young alfalfa is very susceptible to injury, but it becomes more tolerant with age (Fig. 120). Sugar beets are fairly tolerant, but most fruit trees are readily damaged by small concentrations of alkali. In general, citrus and walnuts are found to be the most susceptible of the fruit and nut trees.

Relation of Soils to the Effects of Alkali.—The texture of the soil is interrelated with the toxicity of alkali to plant life. Plants growing in the coarse-textured soils are more seriously damaged by a given amount of alkali than those growing in fine-textured soils. Because of the variability in the alkali tolerance of different crops, it is impossible to state in terms of actual figures what constitutes a serious concentration of alkali.

If much alkali is present in an area, many alkali determinations are made in connection with the soil survey. The exact location where the samples were obtained, as well as the amount present in the surface foot and the average concentration to a depth of 6 feet, are shown on a supplementary alkali map. The presence of alkali is indicated on the map as follows: *A* indicates high concentrations of alkali; *M* moderately affected; *S* slightly affected; and *F* alkali-free. If there is only a small area of land containing alkali, the area so affected is indicated on the soil map by appropriate symbols and no separate alkali map is made.

In rating the agricultural value of alkali soils, special care should be exercised to determine the location of the alkali in the soil profile; if alkali is the only limiting factor in evaluating the land for agricultural purposes, those areas which contain a large quantity of alkali might be rated at less than 25 per cent as compared with alkali-free areas which would be rated at 100 per cent. A strongly affected area usually contains on the average, throughout the profile, 1 to 3 per cent of white alkali salts or much smaller amounts of black alkali. In general, the so-called "alkali-free" areas are those which contain less than 0.2 per cent of white

[1] *Agrostis alba.*

alkali or much less black alkali, uniformly distributed in the soil profile and not concentrated in any one zone.

The presence of white alkali does not usually produce a detrimental structural condition of the soil. However, after areas affected by alkali are reclaimed by flooding and draining, there have been instances when a poor physical condition of the soil was produced. Black alkali produces deflocculation and decreases the permeability of the soil to water.

The Removal of Alkali from Soils.—Even if sparingly used, irrigation water containing large quantities of soluble salts will cause high concentrations of these salts in the root zone. On the other hand, excessive use of irrigation water, as previously mentioned, will raise the water table. An occasional heavy irrigation, not more than once a year, will wash down the white alkali salts from the surface soil either into the drainage water or beyond the normal depth of root penetration. In some districts, the use of certain well waters for irrigation purposes has been abandoned because of their high salt content. Knowing the total salt content of an irrigation water is of no great significance if the kind of salt present is not determined.

The calcium compounds dissolved in the irrigation water react chemically with the soil and improve its permeability and physical condition. For this reason, if the quantity of calcium in the irrigation water is high, the alkali soil will be improved, particularly if the soil contains absorbed sodium. Generally, the use of such types of irrigation water causes little injury to crop plants. If there is a high concentration of sodium in the irrigation water, the soil will absorb the sodium and in time become less permeable. The addition of calcium or sulphur improves the permeability of such soils. The physical condition of the soil is changed from a deflocculated to a granular and mellow one.

The height of the water table varies throughout the year and it is advisable to determine its position at least several times in order to ascertain whether or not it is rising too close to the surface. In most cases, the water table should not be closer than 6 feet.

Certain crops, such as English walnuts, grow best if the soil is at least 20 feet deep, which means that the water table should never come within 20 feet of the surface at any time of the year for this particular crop. In many sections where alkali has accumulated since farming was started, the water table has been

raised by overirrigation until it is less than 6 feet from the surface.

When alkali first appears in the soil in excessive amounts, immediate steps should be taken to prevent its spread. There are regions in the irrigated portions of the western United States that were very productive when first irrigated. Within a period of less than 25 years, however, alkali salts have accumulated in such large amounts that these soils now produce little except poor pasture.

Since alkali salts are usually associated with a high water table, it is essential that first attention be given to the source of the water that has produced the high water table. When the alkali-affected area lies adjacent to a slope, it may be advisable to put in a deep ditch at the base of the slope to act as an intercepting drain. This prevents seepage water from the hillside from raising the water table and bringing alkali salts into the lower land. If the high water table is caused by seepage from irrigation ditches, it may be feasible to waterproof the bottom and sides of these ditches.

Drainage can be provided in several ways: by open drains or ditches; by covered drains, such as tile; or by means of pumping, if the water moves down quickly from the water table near the surface to a deeper porous stratum. Drainage simply removes excess water and provides a deeper root zone in addition to reducing the concentration of alkali in the surface soil. In many instances, such drainage water can be used for irrigation purposes, but the use must be determined by one who is familiar with the characteristics of the various soils and by the composition of such drainage water. Because water moves very slowly through fine-textured soils, it may not be practical to try to reclaim such soils if they contain a large amount of alkali, since it would be necessary to install a large number of drainage lines close together in order to lower the water table.

Where black alkali is present, it is also essential to apply larger quantities of gypsum, sulphur, and alum on the more deflocculated fine-textured soils than on the more pervious coarse-textured ones. Thus, the cost of reclamation is considerably increased.

In irrigated soils, it is the best practice to apply water only to the depth to which the roots normally extend. The depth of penetration of the irrigation water can be determined by exam-

ining the soil, several days after irrigation, by means of a soil auger, or soil tube. A 6-foot soil auger, or soil tube, is generally used in the irrigated regions; but where there are deeper rooted

FIG 121 —Condition of white alkali soil before reclamation was started Photographed in 1929 (*Courtesy of W P Kelley*)

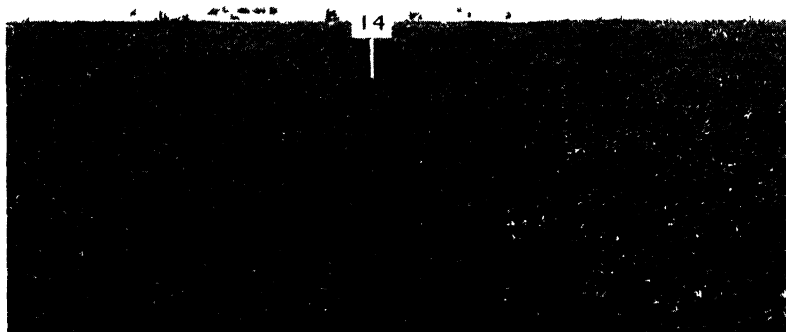



FIG 122 —Reclamation of white alkali soil by drainage and leaching only. Alfalfa on an area that was leached in 1929 and 1930 Photographed in 1931. Compare with Fig 121 (*Courtesy of W P Kelley*)

crops, such as well-established alfalfa fields or orchards such as English walnuts, it is advisable to examine the soils to a greater depth.

The injurious effects of white alkali can usually be eliminated by flooding and drainage, particularly if either the soils or the irrigation water contain a fair supply of soluble calcium salts; but black alkali soils must receive special treatment (Figs. 121 and 122). The addition of chemicals, such as alum, sulphur, or gypsum, to black alkali soils will hasten their reclamation by flooding and drainage.

FIG. 123.—Alfalfa on black alkali soil that had been treated with sulphur. The sulphur was applied in July, 1927 and during the rest of that year the soil was irrigated and cultivated. Hubam clover was planted the first season after the sulphur had been added and this crop was plowed under in September, 1928. The alfalfa was sown Feb. 21, 1929, and photographed May 15, 1929. Compare with Fig. 120. (*Courtesy of Edward E. Thomas.*)

The amount of any of the previously mentioned chemicals that should be applied to black alkali soils depends upon the amount of alkali present and the nature of the soil profile. The character of the latter will determine the rate of water penetration. Water penetrates rapidly through the coarse-textured strata and slowly through the fine-textured layers, such as clays. Moreover, these clay layers will be deflocculated considerably by black alkali. In some experimental areas, large quantities of gypsum, 10 tons or more to the acre, have been used, and the soil then leached by flooding and draining before satisfactory crops were produced.

Marked improvement has been obtained, in some instances, by the application of 1,000 pounds of fine sulphur.

When sulphur is used on black alkali soils, the sulphur is oxidized by soil organisms. Since oxidation is necessary in order that the sulphur produce a favorable effect, it will be several months before much improvement will be noticed (Fig. 123). It may be advisable to use inoculated sulphur on some soils, but most of them are already supplied with the necessary oxidizing bacteria. The effect of sulphur is to increase the soluble calcium content of the soil and thus make it more permeable by flocculating the finer soil particles.

The cost of the chemicals suggested for the treatment of black alkali soils will vary in different sections, and the decision as to which one to use can be made for each district only after a thorough study of the factors mentioned. At Fresno, Calif., Kelley[1] obtained as good results from the use of 1,000 pounds of fine sulphur as from larger amounts. In that district, good results were also obtained by using alum and gypsum, but the cost was higher.

The Alleviation of Harmful Effects of Alkali.—Permitting soils to dry out increases the concentration of salts in the soil solution. Some crops have been grown successfully on land originally containing alkali that later was concentrated in the surface soil by light irrigation. Such irrigation kept the soil moist and the concentration of alkali sufficiently dilute so that some crops have been produced where none grew before.

By irrigating Bermuda grass, or other pasture grasses or by the addition of farm manure, the physical condition of the soil can be improved. Such improvement is produced by the reaction with the alkali salts of the carbon dioxide, given off by the roots of the plants and produced when the manure or other organic matter undergoes decay. The carbon dioxide increases the solubility of the calcium in the soil, and the calcium reacts with the black alkali, so that the latter can be more readily leached out of the soil (Figs. 124 and 125).

A green manure crop, such as *Sesbania*, a legume that is very tolerant to alkali, has been turned under on some alkali lands. This practice has been found to be very effective in promoting the growth of some irrigated crops.

[1] KELLEY, *op. cit.*

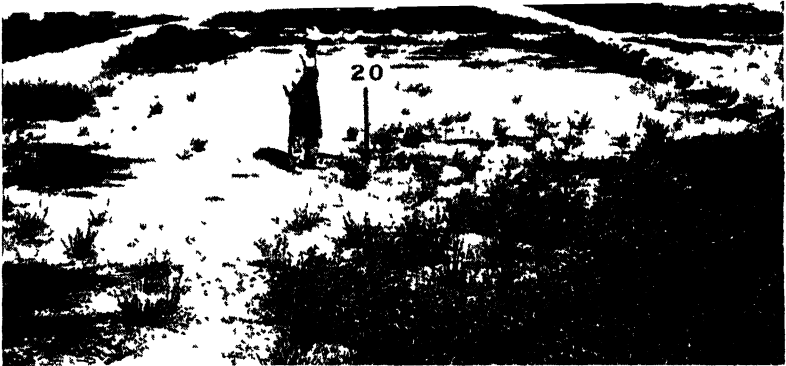



FIG. 124.—Condition of alfalfa in 1926 on black alkali soil that had been flooded and drained but no chemicals had been added. (*Courtesy of W. P. Kelley.*)

FIG. 125.—Same area as shown in Fig. 124, photographed in 1932. Note the marked improvement in the area in six years. (*Courtesy of W. P. Kelley.*)

THE "ALKALI" SOILS OF HUMID REGIONS

The acreage of so-called "alkali"[1] soils in humid regions is small in comparison with that in arid and semiarid ones. Moreover, the problem is less acute in the humid than in the drier regions. The alkali soils of the humid regions in this country are

FIG. 126.—Corn on humid "alkali" soil. Many snail shells and fragments of shells are present on some of these so-called "alkali" soils. The stand of corn was very poor on this spot. This plant is very short in comparison with the normal diameter of the stalk. Corn often fails on these spots. (*Courtesy of Illinois Agr. Exp. Sta.*)

confined in the main to swampy areas or spots where seepage may have brought soluble materials to the surface. Upon evaporation, the soluble salts accumulated in the surface soil and persisted in spite of leaching. In the humid region, these so-called

[1] It should be stated at the outset that "alkali" is a popular rather than a correct scientific term for this material in humid regions. In some of the humid "alkali" areas, the soil has an alkaline reaction. In others, it may be slightly acid; but the growth of crops is abnormal, and the farmer does not distinguish between the two conditions.

"alkali" spots usually occur as small areas in otherwise productive soils. In some old swampy sections, however, rather large areas occur. There are areas of 1 square mile or more in central Illinois. In places, the soil is unusually loose and friable and is dead gray in color instead of the usual dark brown to black, characteristic of heavy swamp soils. Many fragments and whole snail shells are present and contribute toward the grayish color of this soil. On some soils of this character, corn fails completely. On other areas, the plants are abnormal in color, height, and width of leaves (Fig. 126). Considerable variation exists in the composition of this humid alkali and in the degree of its harmfulness to crops.

The Formation and Composition of Humid Alkali.—In general, humid alkali is associated with swamps or shallow, recent glacial lakes, some of which may have been more or less drained by nature, others by ditching in the reclamation of relatively large swamps.

According to Stevenson, Brown, and Boatman,[1] the water of the swamps contained a rather high concentration of salts, which upon drainage remained in the soil. Since swamps are flat and often have depressions or pockets, little surface runoff from the area occurred to remove the salts; and as evaporation took place, the salts accumulated in and on the surface soil, often to the extent of forming a white incrustation.

The proportions of the salts present are quite variable. Calcium and magnesium carbonates and bicarbonates are prominent. In some places, much nitrate and in others much sulphate are found; and sodium, which is so prominent in arid alkali, is found in higher proportions than in normal humid soils. These factors tend to explain why any one treatment is not the universal remedy for the troubles that attend the farming of alkali soils in humid areas. Magnesium compounds, however, are credited with causing much of the damage to crops.

The Remedies for Alkali Conditions in Humid Regions.—At least three remedies have been suggested: (1) drainage; (2) the

[1] STEVENSON, W. H., P. E. BROWN, and J. L. BOATMAN, The Management of Peat and Alkali Soils in Iowa, *Iowa Agr. Exp. Sta., Bull.* 266, pp. 96–100, 1937.

See also P. E. Brown, A. M. O'Neal, and H. R. Meldrum, *Iowa Agr. Exp. Sta., Soil Survey Rept.*, 69, Pocahontas County, pp. 33–34, 1933.

application of potash salts and phosphorus, if needed; (3) the addition of fresh organic matter.

The Iowa investigators recommended thorough effective drainage for the relatively quick removal of these soluble salts from the soil. In Illinois, Hopkins, Readhimer, and Fisher[1] applied various treatments to peaty alkali soils over a period of 5 years. The treatments were manure at rates of 6 and 12 tons an acre, respectively, potassium as 148 pounds an acre of potassium

FIG. 127.—Effect of potash on corn in Indiana. The corn on the left received 120 pounds to the acre of 0–8–24, that in the middle 20 per cent superphosphate, and that on the extreme right 120 pounds of 0–20–20 fertilizer. Potash obviously is distinctly beneficial. There is some evidence that the plant growth on this untreated alkali soil is similar to that shown in Fig. 126, Illinois. (*Courtesy of American Potash Institute, Inc.*)

sulphate, and gypsum at rates of 2, 4, 8, and 16 tons an acre, once for the five years, 1907 to 1911. More potassium was applied in 12 tons of manure than in the potassium sulphate. On the average, gypsum depressed the yields of both corn and wheat but did not materially affect the yields of oats. The 12-ton application of manure did not materially increase yields over the 6-ton application. Over the 5 years, two untreated check plots produced 13.5 bushels of corn on the average, the

[1] HOPKINS, C. G., J. E. READHIMER, and O. S. FISHER, Peaty Swamp Lands; Sand and "Alkali" Soils, *Ill. Agr. Exp. Sta., Bull.* 157, 1912.

manured plots (average of 6 and 12 tons) produced 46.6 bushels, and the ones given potash produced 46.1 bushels an acre on the average. For corn, therefore, applications of manure and potassium sulphate were equally effective, but oats and wheat did not respond uniformly to applications of potassium. No phosphatic fertilizer was used; but, of course, the manure carried small amounts of it. Lack of available potassium appears to have limited yields of corn on this alkali peaty soil. In the work cited, Stevenson, Brown, and Boatman found that the peaty soils of Iowa were distinctly deficient in phosphorus.

In the Iowa work on mineral alkali soils, potassium increased yields materially, but phosphorus was ineffective. Four hundred pounds of muriate of potash to the acre doubled the yields and produced six times as much actual sound corn as did the untreated soil. Owing to the variations cited, local tests with potassium and phosphorus appear desirable (see Fig. 127).

The application to humid alkali soils of fresh, strawy horse manure has proved highly beneficial. Growing rye, oats, sweet clover, and other legumes and turning them under in the green state also are advantageous. This decaying green material aids in the removal of the soluble salts and, in addition, appears to reduce the detrimental effects of the soluble salts.

Questions

1. Where are the alkali soils located in the United States, and why are they found there?

2. What are the more harmful alkali salts?

3. Distinguish between black and white alkali.

4. Discuss the relative alkali tolerance of different crops.

5. What relations exist between soils and the effects of alkali on crops?

6. Outline practicable methods for the removal of alkali from soils.

7. Indicate how to alleviate the harmful effects of alkali on crops.

8. Where do so-called "alkali" soils occur in humid areas in the United States?

9. Discuss the formation and composition of humid alkali.

10. Outline the remedies for the alkali of humid areas.

CHAPTER XII

NITROGEN AND ITS IMPORTANCE TO THE FARMER

Nitrogen is used in relatively large quantities both for vegetative growth and for the production of seed. Nitrogen constitutes approximately three-quarters of the atmosphere by weight and nearly four-fifths by volume. Since nitrogen is abundant, it becomes the joint task of the fertilizer manufacturer and the farmer to fix it and prepare it for use by crops.

LOSSES OF NITROGEN FROM THE SOIL

Nitrogen is lost from the soil in crops, by drainage, by burning, and as ammonia and elemental nitrogen.

In Crops.—Crops use much nitrogen in their growth, and when they are harvested and sold from the farm the nitrogen in them is lost to the soil. According to Table 18, page 103, the average loss from two soils is approximately 49 pounds to the acre. Though open to possible criticism, this figure is arrived at by deducting the nitrogen lost in drainage from the cropped land from that lost from the fallow soil. By computation, using the average composition of crops in a rotation of corn, oats, clover, and timothy, the author has arrived at the data in the lower part of Table 19 for the part of the crops harvested and removed from the land. These quantities are calculated from a yield of 50 bushels of grain of corn and oats, including 3,000 pounds of corn fodder and 2,500 of oat straw (including stubble) and 2 tons of timothy hay. If the fodder is left on the soil as it is when corn is harvested for grain, the average nitrogen content of the crops is reduced accordingly. The nitrogen in the clover is assumed to have been obtained by symbiotic fixation. From these figures, it may be observed that the average crop in this rotation used much more nitrogen for growth than was lost in the drainage from this soil when it was growing crops of a similar rotation.

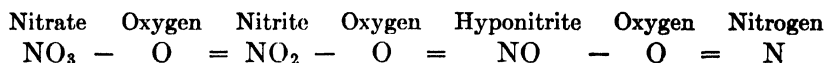
By Drainage.—It has long been known that nitrogen is lost from soils in the drainage water. Much is lost from bare or fal-

low soils and less from cropped ones. In the Cornell lysimeter work (Table 18, page 103), the average annual loss of nitrogen from two cropped soils, one over a period of 15 and the other over a period of 10 years, was 7.2 pounds an acre. In comparison with the loss of nitrogen from bare soil, this loss is slight indeed.

By Burning.—By burning any form of crop residues such as stubble, corn, cotton, broom-corn stalks, or other leftovers from crops, the nitrogen in them is released to the atmosphere and thus lost to crops. Such losses occur at irregular intervals rather than annually and, therefore, need not enter definitely into calculations unless burning is a regular practice (Fig. 22).

As Ammonia and Elemental Nitrogen.—Nitrogen appears to be lost by these means. A few years ago, Wilson[1] found by actual measurement an evolution of ammonia of 2 to 10 parts per million of soil in 4 or 5 days. If 5 parts per million of ammonia or 4.1 of nitrogen are used as an average for the determinations, these soils lost nitrogen as ammonia at the rate of 8 pounds an acre in less than 1 week. If this rate continued throughout the growing season, a heavy loss of nitrogen would take place in this way.

Moreover, evidence is not lacking that nitrates, NO_3, are reduced to nitrites, NO_2, under conditions of poor aeration. It appears, also, that the oxygen may be split off from nitrites with the consequent liberation to the atmosphere of free or elemental nitrogen. This change is thought to happen in three steps as follows:

Nitrate		Oxygen		Nitrite		Oxygen		Hyponitrite		Oxygen		Nitrogen
NO_3	$-$	O	$=$	NO_2	$-$	O	$=$	NO	$-$	O	$=$	N

In Saskatchewan, Shutt[2] reported a loss of 1,486 pounds of nitrogen in 22 years in addition to that recovered in the crops grown. Since little drainage occurred there, the nitrogen could not have been leached out of the soil. The annual "dead loss" of nitrogen, therefore, was 68 pounds an acre a year over that period.

At Rothamsted, Russell reported on the fate of nitrogen in the soil on Broadbalk wheat field from 1865 to 1914. Soil that

[1] Wilson, J. K., unpublished data, Cornell University Agricultural Experiment Station, 1939.

[2] Shutt, Frank T., Western Prairie Soils, *Cent. Exp. Farm, Canadian Dept. Agr., Bull.* 6, *Second Ser.*, p. 16, 1910.

received 14 tons of manure annually lost 145 pounds (net) of nitrogen a year on the average. The soil that received nothing gained 2 pounds a year. Each of two plots that received 86 pounds of fertilizer nitrogen annually lost 51 pounds a year on the average for the 49 years. These losses of nitrogen appear to be high; yet similar data have been reported by a number of workers both in this country and abroad.

ADDITIONS OF NITROGEN TO THE SOIL

Nitrogen is added to the soil in several important ways: in the rainfall; by nonsymbiotic soil organisms; by symbiotic ones in conjunction with legumes; and in crop residues, farm manures, and fertilizers.

In Rainfall.—The amounts of nitrogen brought to the soil in rainfall vary somewhat from place to place. At Ithaca, N.Y., Wilson[1] found an average of 7.9 pounds of nitrogen an acre brought to the soil in rain and snow annually over a period of 11 years. It should be pointed out, however, that the figures were much higher during the first 3 years than later. An average of about 5 pounds of nitrogen an acre a year, received by the soil from precipitation at Ithaca, is more nearly a true picture of actual conditions. Less nitrogen is brought to the earth in rain in some locations and somewhat more in others. An average of between 5 and 7 pounds of nitrogen an acre annually may be expected from precipitation.

By Nonsymbiotic Organisms.—The nonsymbiotic, or free-living, nitrogen-fixing organisms, are represented by the *azotobacter* and other groups. They work to best advantage in soils that have a pH around 6.0. If the pH drops much below this point, they are inhibited. Their high lime requirement would appear to limit the activities of azotobacter on many acid soils. Keeping soils in condition for producing a good yield of red clover, therefore, is the minimum requirement with respect to liming for these organisms, and fortunately this condition is favorable for best results with many crops.

The fixation of nitrogen by azotobacter is called *azofication.* The quantity of nitrogen fixed annually by these organisms varies with conditions. At the Cornell University Agricultural

[1] WILSON, B. D., Nitrogen and Sulfur in Rainwater in New York, *Jour. Amer. Soc. Agron.*, Vol. 18, pp. 1108–1112, 1926.

Experiment Station, Lyon and Wilson[1] found that grassland from which no crop was taken gained 32 pounds of nitrogen an acre a year on the average for 11 years, exclusive of that from rainfall. A loss of 5 pounds of nitrogen occurred when the grass was harvested. In England, around 36 pounds of nitrogen an acre a year, exclusive of that in rainfall, accumulated in undisturbed grass during a period of 20 years. In both the Rothamsted and Cornell work, the grass and other nonleguminous plants were left on the land. The only difference was that at Cornell the grass was mowed and left on the land. To an extent, these groups of soil organisms carry on their work under intertilled crops, and they appear to function whenever conditions are favorable for them.

Lyon and Bizzell[2] reported an average fixation of 17 pounds of nitrogen to the acre in a soil on which barley, rye, and oats were grown during 10 years without any legume, whatever. In spite of these findings, Thom and Smith[3] state, "There is some question as to the importance of azotobacter to soil fertility because of their small numbers." The high pH that they require is a factor in limiting the activity of azotobacter in many soils. The fact of real importance to the farmer is the fixation by some process of important quantities of nitrogen in the soil.

By Symbiotic Organisms.—Great variations are reported as to the quantity of nitrogen added to the soil by legumes. Some workers report actual losses following long-term growth of certain legumes. In contrast, other workers have reported additions of 50 to 100 pounds to the acre annually as an average for a period of years. At Geneva, N.Y., Collison, Beattie, and Harlan,[4] found up to 260 pounds of nitrogen an acre a year to have been fixed by alfalfa. And Lyon and Bizzell reported on the fixation of nitrogen by several leguminous crops, separately and in mix-

[1] LYON, T. L., and B. D. WILSON, Some Relations of Green-manures to the Nitrogen of the Soil, *Cornell Univ. Agr. Exp. Sta., Mem.* 115, pp. 27–28, 1928.

[2] LYON, T. L., and J. A. BIZZELL, A Comparison of Several Legumes with Respect to Nitrogen Accretion, *Jour. Amer. Soc. Agron.*, Vol. 26, pp. 654–656, 1934.

[3] THOM, CHARLES, and N. R. SMITH, Fauna and Flora of the Soil, *Yearbook of Agriculture*, 1938, p. 943, U.S. Department of Agriculture.

[4] COLLISON, R. C., H. C. BEATTIE, and J. D. HARLAN, Lysimeter Investigations—III, *New York State Agr. Exp. Sta., Bull.* 212, 1933.

ture with other legumes and with grain crops. These data are given in Table 36.

TABLE 36.—NITROGEN FIXATION BY LEGUMES*
(Pounds of Nitrogen in 2,500,000 lb. of Soil)

Crops	Nitrogen in all crops harvested, in 10 years, pounds per acre	Nitrogen in soil, gain or loss, in 10 years, pounds per acre	Apparent average annual nitrogen fixation, pounds per acre
Red clover	868	532	146
Alsike clover	830	595	136
Red and alsike clover	1,054	577	163
Alfalfa	1,804	607	241
Sweet clover	1,214	420	163
Sweet clover and vetch	1,155	410	156
Soybeans	1,058	− 42	102
Peas and oats	493	− 32	46
Field beans	672	−100	57
Vetch and wheat	549	97	65
Barley, rye, or oats	233	− 52	17
Alfalfa each year	2,179	505	268

[1] LYON, T. L., and J. A. BIZZELL, A Comparison of Several Legumes with Respect to Nitrogen Accretion, *Jour. Amer. Soc. Agron.*, Vol. 26, p. 653, 1934.

It should be noted in the first place that these legumes were alternated with rye or barley during the 10 years of the experiment and in the second that the alfalfa at the end of the table was grown continuously.

The gains in nitrogen by the soil on which biennial or perennial legumes were alternated with grains are notably large. That soybeans, field beans, and vetch produced considerable losses is also notable. In fact, the loss from the soil growing field beans was greater than that from the soil growing barley, rye, or oats without legumes.

The relative effectiveness of the red and alsike clover mixture in the fixation of nitrogen, when compared with either red or alsike grown alone, is somewhat remarkable. This should not be interpreted to mean that this mixture should always be sown in preference to red or alsike separately. It does suggest, however, that this mixture is preferable under soil conditions that are

moderately favorable for both clovers. A fixation of 80 to 100 pounds an acre annually for red and alsike clover, or mixtures of them, and of 150 to 200 for alfalfa may be regarded as highly satisfactory. It may be repeated that the maintenance of conditions favorable for the growth of these leguminous crops aids greatly in making them effective in the fixation of nitrogen.

Fred, Baldwin, and McCoy have collected widespread data on the amounts of nitrogen fixed by different legumes as determined by various investigators over a wide area. Their figures are given in Table 37.

TABLE 37.—AMOUNTS OF NITROGEN FIXED SYMBIOTICALLY PER ACRE ANNUALLY BY VARIOUS LEGUMINOUS CROPS*

Investigators	Place	Crop	Pounds of nitrogen
Arny and Thatcher, 1915	Minnesota	Alfalfa	113†
Arny and Thatcher, 1917	Minnesota	Sweet clover	117
Whiting, 1915	Illinois	Alfalfa	132
Fred and Graul, 1916	Wisconsin	Alfalfa	64†
Graul and Fred, 1922	Wisconsin	Alfalfa	94†
Shutt, 1906, 1910	Canada	Red clover	75–150
Shutt, 1912	Canada (average 10 years)	Red clover	51
Whiting, 1915	Illinois (4 tons)	Red clover	106
Graul and Fred, 1922	Wisconsin	Red clover	100
Duggar, 1898	Alabama	Hairy vetch	79
Whiting, 1915	Illinois	Cowpea	86
Breal, 1889	France	Bean	87
Fred, 1921	Wisconsin	Soybean	57
Fred and Graul, 1919	Wisconsin	Soybean	108
Albrecht, 1920	Illinois	Soybean and cowpea	107
Moore, 1905	16 states of United States	Mixed legumes	122
Mertz, 1918	California	Mixed legumes	94
Hartwell and Pember, 1911	Rhode Island	Mixed legumes (2 crops)	120

* FRED, E. B., I. L. BALDWIN, and ELIZABETH McCOY, "Root Nodule Bacteria and Leguminous Plants," p. 218, Madison, Wis., 1932.

† Average figure.

As an average of these data, alfalfa fixed 101 pounds an acre annually, sweet clover (one figure) 117, red clover 91, and annual

legumes (including hairy vetch) 89 pounds of nitrogen. The figures for the annuals are much higher and for alfalfa lower than the data in Table 36. Differences in soil and climatic conditions undoubtedly account in part for such variations.

Methods of Inoculating Legumes.—*Inoculation* means bringing the right nodule bacteria into contact with the seed so that nodulation will take place quickly and freely. The right bacteria may be present in the soil, or they may be introduced. A method used earlier was the transfer of topsoil from a field on which the particular legume had been grown recently. This presupposed that the legume was inoculated and had produced nodules in abundance. This is a laborious and a less effective method than the newer ones.

An easier method is the use of the so-called "artificial" culture. The bacteria are grown and transferred to moist sandy soil as a carrier, or the organisms may be "seeded" onto a moist semisolid culture medium. On this, they multiply until removed for application to the legume seed.

In either case, the organisms are taken up in a small quantity of water. This in turn is poured over the dry legume seed which is then shoveled several times in order to spread the organisms over all seeds. The seed is then dried slowly in shade, because bright sunshine is injurious to the organisms. When dry, the seed is ready to be sown in the usual manner.

Benefits of Inoculating Leguminous Seeds before Planting.—Farmers have long been aware that inoculation of legumes

TABLE 38.—EFFECT OF INOCULATING LEGUMES ON YIELD OF DRY MATTER*

pH	Increases			
	Red clover, per cent	Alfalfa, per cent,	Red kidney beans (seeds), per cent	Peas (ripe seed), per cent
7.59 (average of 6 tests), limed.....	39.9	11.0	9.2	14.0
5.4 (average of 6 tests), unlimed....	32.2	18.0	5.0	25.7

* WILSON, J. K., and E. W. LELAND, The Value of Supplementary Bacteria for Legumes, *Jour. Amer. Soc. Agron.*, Vol. 21, pp. 574–586, 1929.

increases yields. The specific influence of inoculating varies widely with soil types and their condition with respect to acidity. Furthermore, the different legumes themselves show wide variations. Wilson and Leland reported on the effect of inoculation on yields of four legumes. Their data are given in Table 38.

Many factors enter into consideration of these data. These increases, however, certainly suggest, and very strongly, the

Fig. 128.—Effect of inoculation on growth of red clover. Legumes on whose roots no nodulation occurs function the same as do nonlegumes. The lack of inoculation on the clover on the left accounts for the difference in growth. (*Reproduced by permission of the University of Wisconsin Press from E. B. Fred, Elizabeth McCoy, and I. L. Baldwin, "Root Nodule Bacteria and Leguminous Plants,"* 1932.)

advantage of inoculating red clover (Fig. 128), alfalfa, and peas. In fact, the cost of inoculating is so slight and the increase produced so marked that inoculating these crops whenever and wherever seeded appears warranted. Moreover, Whiting and Fred[1] report that the inoculation of peas increased the yield of actual peas, the proportion of the higher grades (Fig. 129), and the percentage of nitrogen in the peas. Moreover, the nitrogen

[1] Whiting, A. L., and E. B. Fred, Inoculated Seed Increased Yield and Quality of Legumes, *Wisconsin Agr. College, Extension Circ.* 194, pp. 1–7, 1926.

acquired through inoculation retarded ripening or hardening so that the peas continued in fancy condition longer than did the product of uninoculated seed. Inoculation would appear to be justified even if it produced much smaller increases in yields.

Another advantage of inoculating legumes is the increase in their nitrogen content. Arny and Thatcher[1] found that the tops of inoculated alfalfa had 2.56 per cent of nitrogen as compared with 1.51 per cent in the uninoculated. For the roots the corresponding figures are 2.14 and 0.71 per cent of nitrogen. The tops

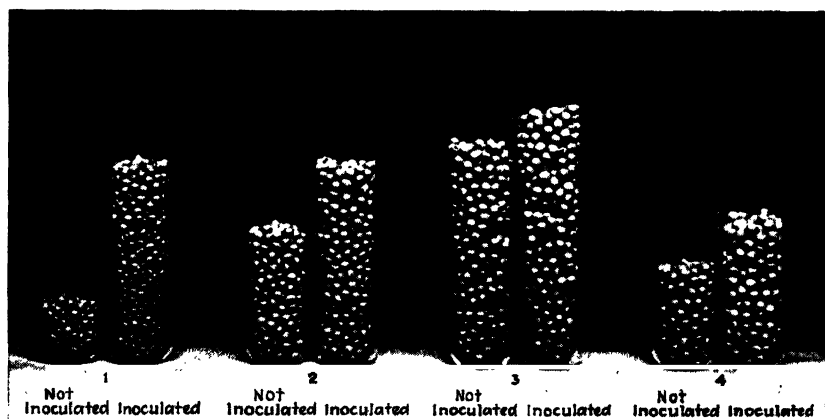



FIG. 129.—Effect of inoculation on yield and grade of cannery peas. Inoculation was particularly effective in increasing both yield and proportion of the higher grades of actual peas. (*Reproduced by permission of the University of Wisconsin Press from E. B. Fred, Elizabeth McCoy, and I. L. Baldwin, "Root Nodule Bacteria and Leguminous Plants,"* 1932.)

of inoculated sweet clover contained 2.36 per cent, and those of the uninoculated 1.37; the roots of the inoculated 1.68 and those of the uninoculated 0.89 per cent of nitrogen. The increase is probably the result of additional fixation. The higher nitrogen content accelerates the decomposition of the roots and stubble and therefore facilitates the desirable turnover and repeated use of the nitrogen in these residues.

Cross Inoculation.—In the past, legumes have been grouped according to their acceptance of the nodule organism from the other members of their group. This acceptance has been called

[1] ARNY, A. C., and R. W. THATCHER, The Effect of Different Methods of Inoculation on the Yield and Protein Content of Alfalfa and Sweet Clover, *Jour. Amer. Soc. Agron.*, Vol. 9, pp. 135, 1917.

cross inoculation. Owing to the doubts raised by Wilson[1] concerning the conventional grouping, no suggestions are made here. A broadening rather than a narrowing of the groups appears to be in the offing.

In Crop Residues.—Some nitrogen goes back into, or stays in, the soil as residues. For example, roots of many crops stay in the soil and are particularly beneficial because of their uniform distribution. According to the figures in Table 13 (page 75), the stubble and roots of a crop of oats weigh about 3,800 pounds to the acre. If this material contains approximately the same proportion of nitrogen as oat straw, the stubble carries 24 pounds of it to the acre. Red-clover stubble amounts to more than two times and alfalfa to nearly three times the quantity of oat stubble; moreover, the leguminous stubbles contain a much higher percentage of nitrogen than do the stubbles from the grains. On the basis of a rotation of such feed crops as corn, small grain, red clover, and timothy, it is estimated that as high as 45 pounds of nitrogen a year on the average is thus left in the soil. About 30 pounds may be a better estimate for a fairly wide range of soils of average productivity.

Under normal conditions in this country, the stubble ought not to be burned, but turned back into the soil. In the Orient we are told that the stubble and roots are collected for use as fuel. Although this use of stubble is necessary under Oriental conditions, it should generally be plowed under as a source of nitrogen and organic matter in this country.

In Farm Manures.—Farm manures are a valuable source of nitrogen for use on the soil. Their conservation and utilization are treated in the next chapter. Average farm manure carries 10 pounds of nitrogen to the ton. If 10 tons of manure to the acre are returned to the soil once in 4 years, this is an average addition of 25 pounds of nitrogen an acre a year during the rotation.

In Fertilizers.—For feed crops, fertilizers are used mainly to supplement the nutrients in the soil. On much of the cropped land in the United States, little commercial nitrogen is used. On the average for the entire United States, the amount of nitrogen used to the acre is small. Potatoes, cabbage, tobacco,

[1] WILSON, J. K., A Relationship between Pollination and Nodulation of the Leguminoseae, *Jour. Amer. Soc. Agron.*, Vol. 31, pp. 159–170, 1939.

cotton, and truck crops, of course, do receive fertilizer nitrogen in substantial amounts; and these naturally constitute important additions to the soil so treated.

CHANGES IN THE NITROGEN OF ORGANIC MATTER IN THE SOIL

The changes in organic matter that is added to the soil are extremely complex. Only the broad outline is considered here.

After alfalfa After timothy

Fig. 130.—Effect of alfalfa on growth of corn. Since other conditions in this soil were held uniform the difference in growth of corn is attributable to the effect of the alfalfa as compared with that of the timothy. Alfalfa increased the growth of corn 44 per cent. (*Courtesy of E. W. Leland, Dept. of Agron., Cornell Univ. Agr. Exp. Sta.*)

The nitrogen was originally in the form of protein and related compounds. In order to obtain from the protein what they need, organisms break it down, with ammonia as one of the immediate products. Ammonia, in turn, is oxidized to nitrate through one or more steps. And as nitrate, many plants take

up their main supply of nitrogen. However, it is believed now that considerable nitrogen is used in the form of ammonia.

From the preceding paragraph, it appears that nitrogen in soil organic matter goes through the following stages:

$$\text{Complex nitrogen compounds} \rightarrow \text{Ammonia} \rightarrow \text{Nitrite} \rightarrow \text{Nitrate}$$
$$\text{Protein} \rightarrow NH_3 \rightarrow NO_2 \rightarrow NO_3$$

EFFECTS OF LEGUMINOUS AS COMPARED WITH NONLEGUMINOUS RESIDUES

Upon being turned under, leguminous residues because of their narrow C:N ratio, are readily broken down. The nitrogen in them soon appears as nitrates which are taken up at once by

After clover After timothy

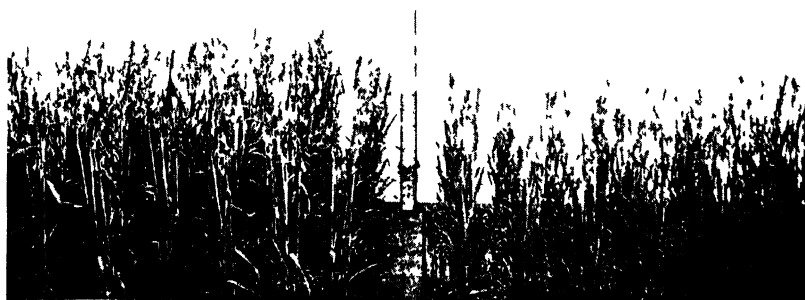



FIG. 131 —Effect of clover on growth of grain. The oats on the left followed clover, those on the right, timothy The difference in growth is the result of the nitrogen fixed by the clover and left in the soil The production of oats following clover was more than twice that after timothy This is typical of the effect of legumes on the growth of a nonlegume following them.

growing crops. In contrast, mature nonleguminous material, such as timothy stubble, because of its wide C:N ratio is not so readily broken down as are leguminous materials. In fact, in in order that the organisms may decompose timothy stubble, they must draw on the soil or fertilizer applications for nitrogen. This may create a temporary shortage of nitrogen for the crop. Even though soils that have produced alfalfa and timothy may have approximately the same nitrogen content, corn following alfalfa produces a more vigorous growth and a larger yield than that following timothy (Fig. 130). This condition holds for corn, wheat, and oats following leguminous and nonleguminous crops, respectively (Fig. 131; see also Fig. 132).

The data reported by Lyon in Table 39 have a bearing on this point. The yields shown in the second column represent the

After clover — After timothy — After clover

FIG. 132.—Comparison of effects of clover and timothy on the yield of hay. The rotation is one of four years. The hay on the right and left followed clover in a rotation of corn, oats, clover, and timothy. The hay in the center followed timothy in a rotation of corn, oats, timothy, and timothy. The yield following clover was more than twice as great as that following timothy.

products that were harvested and taken off the land. Of the biennial clovers and alfalfa, a considerable quantity of roots and

TABLE 39.—AVERAGE ANNUAL YIELDS OF LEGUMES AND MIXTURES AND OF CEREALS FOLLOWING THEM*

Legume or mixture	Yield per acre, pounds	Yield of cereal after legume or mixture, pounds
Red clover	4,123	5,144
Alsike clover	4,092	5,126
Alfalfa	8,842	6,068
Sweet clover	4,035	5,119
Vetch and wheat	4,700	2,805
Red and alsike clover	5,466	5,243
Sweet clover and vetch	4,294	4,951
Soybeans	5,873	2,953
Peas and oats	3,720	2,907
Field beans	4,247	2,760
Cereals only	.....	2,214

* LYON, T. L., The Residual Effects of Some Leguminous Crops, *Cornell Univ. Agr. Exp. Sta., Bull.*, 645, pp. 6, 7. 1936.

stubble remained in and on the soil. The yields of the cereal following these legumes were outstandingly high (nearly twice as high) in comparison with those following the annual legumes and vetch. The yield of the cereal following 9 years of grain crops was only 642 pounds less than the average yield following the annual legumes. This suggests the rather poor fixation by this group of legumes.

THE NITROGEN CYCLE IN CROPPED SOILS

A beginning of the nitrogen cycle may well be made with the soil in its natural condition. Nitrogen is lost through the plants grown on and removed from the soil, in drainage water, by washing off as organic matter from the surface, by burning (for not only is surface organic matter thus destroyed but also some plant materials in the immediate surface of the soil itself), and by the escape of nitrogen in gaseous form. Returns of nitrogen occur when the manure resulting from the feeding of crops is put back on the fields where the crops were grown and the stubble and roots go back into the soil as residues. Nitrogen is fixed in the soil by free-living organisms and by symbiotic ones, as well. And the nitrogen in leguminous material goes into the soil as manures and residues unless the crop is sold from the farm. In addition, a small amount of nitrogen is brought to the soil in rain water.

Soil organisms act upon the organic matter and render the nitrogen in it available to crops. As crops use this nitrogen, a new cycle is started and one cycle has followed another over the centuries that have passed.

MAINTENANCE OF THE SUPPLY OF NITROGEN IN THE SOIL

Some nitrogen comes to the soil in rain water, and some is fixed by nonsymbiotic organisms in the soil, as stated in the previous section. Legumes, however, have been and probably will continue to be the principal source of nitrogen in arable soils that the farmer controls. Leguminous plants, therefore, are the foundation upon which agriculture rests and upon which man is markedly dependent.

As shown in the preceding pages, legumes vary greatly in their efficiency in the fixation of nitrogen; annuals and winter annuals

are least effective, the biennials are relatively effective, and the perennials slightly superior. On the basis of the nitrogen fixed, as given in Table 37, 80 pounds may be used as a conservative figure for the average annual fixation of nitrogen by legumes.

According to Mehring,[1] the commercial manufacturing plants for the fixation of nitrogen in the United States produced 200,000 tons in 1938. Their rated capacity is 340,000 tons, or 680 million pounds, of nitrogen annually. The production figures seem large; yet they represent only about ½ pound an acre a year for the combined crop, pasture, and range land in farms in the United States.

As previously stated, 80 pounds of nitrogen an acre a year is a conservative estimate of the average yearly fixation by legumes. At this rate of fixation, 5 million acres of average leguminous crops[2] fix a quantity of nitrogen equivalent to the total annual production of chemically fixed nitrogen (1938) in the United States. This acreage of legumes is less than one-twentieth, or 5 per cent, of the area of legumes that good soil-management practices demand. From these figures, it is clear that, if legumes were grown regularly in a 4-year rotation on American farms, these legumes might fix twenty times as much nitrogen as was produced by commercial fixation processes in 1938. The use of legumes to their full capacity in rotations of 3 to 5 years and, in addition, the full use of the commercial factories for the fixation of nitrogen for vegetables and special cash crops should help farmers to maintain the supply of nitrogen in the soil. Such additions to the soil would aid in balancing the annual outgo of nitrogen, and balancing it is essential to a permanent agriculture in this country.

Questions

1. What are the sources of nitrogen in the soil?

2. How is nitrogen lost from the soil?

3. In what practical ways may nitrogen be added to the soil?

4. What quantities of nitrogen to the acre do nonsymbiotic and symbiotic organisms fix annually under different conditions?

5. Can you develop a fairly definite balance sheet for nitrogen on your home farm?

[1] A. L. Mehring of the U.S. Department of Agriculture in a personal communication.

[2] Dr. J. K. Wilson suggested this calculation.

6. What important changes does nitrogen undergo in the soil?

7. Compare the effects of leguminous with those of nonleguminous residues in the soil.

8. Outline the nitrogen cycle in cropped soils.

9. Show how to maintain the supply of active nitrogen in the soils on your land.

CHAPTER XIII

THE PRODUCTION, CONSERVATION, AND UTILIZATION OF FARM MANURES

The production, conservation, and economic utilization of farm manures deserves thorough consideration by farmers and other students of soil-management and crop-production problems. The average-sized livestock farm produces a relatively large quantity of manure annually. If properly conserved and utilized, this manure is an asset of real importance in the maintenance of the productivity of the land. Improvement in the methods of handling and utilizing it may be made on many farms.

Manure a Valuable By-product.—By far the major part of the feed crops grown on livestock farms is fed there. Manure is a valuable by-product of mixed livestock and grain farming. In times past, some farmers have regarded manure as a nuisance, something to be got rid of as easily as possible. Not so with the wise farmer. He protects, preserves, and supplements manure in order that his crops may obtain the greatest benefit from it.

PRODUCTION OF MANURE

The amount of manure produced on different farms varies widely. Some of the influencing factors are: size of farm; productivity of the land or quantity of feed grown or purchased; the kind and quantity of litter or bedding available; and the number, kind, and age of the animals fed on the farm.

Quantity and Kind of Feed.—The total quantity of feed grown, if consumed on the farm, obviously has a strong influence on the production of manure. The kind and digestibility of the feed have an influence too. Corn (grain), for example, is highly digestible; and about one-tenth of the dry matter in it is recovered in the manure. In contrast, coarse, overripe timothy hay is of low digestibility, and nearly two-thirds of it reappears in the

excrement. The relative digestibility of feeds and the recovery of dry matter in the manure for a limited number of trials are given in Table 40.

TABLE 40.—DIGESTIBILITY OF FEEDS AND RECOVERY OF DRY MATTER*

Feeds	Percentage of feed digested		Dry matter in feed recovered in manure	
	Dry matter	Nitrogen	Per cent	Pounds per ton
Pasture grasses	71	70	29	580
Red clover, green	66	67	34	680
Alfalfa, green	67	81	33	660
Mixed hay	61	57	39	780
Red-clover hay	61	62	39	780
Alfalfa hay	60	74	40	800
Oat straw	48	30	52	1,040
Wheat straw	43	11	57	1,140
Corn stover	60	45	40	800
Shock corn	63	42	37	740
Corn-and-cob meal	79	52	21	420
Corn silage	64	49	36	720
Oats	70	78	30	600
Corn	91	76	9	180
Wheat bran	61	79	39	780

* HOPKINS, C. G., "Soil Fertility and Permanent Agriculture," p. 199, Ginn and Company, Boston, 1910.

In Table 41 is given the proportion of the plant nutrients that are recovered in the manure from different animals and under different conditions. Several points deserve attention here. Twice as much of the organic matter in the "coarse-roughage" ration is recovered in the manure as from the "heavy-concentrate" ration. Compared with dairy animals, work animals retain very little of the nitrogen from their feed. Young, growing animals retain about 65 per cent of the phosphorus, and dairy ones 50 per cent, as compared with 25 per cent for work animals. The differences in the retention of potash are slight, the work animals retaining only about 10 per cent.

Quantity and Kind of Bedding.—Many different materials are used for bedding. Wheat, oat, barley, and rye straw, however,

TABLE 41.—THE PERCENTAGES OF THE NUTRIENTS IN FEED THAT ARE RECOVERED IN THE MANURE FROM DIFFERENT TYPES OF ANIMAL*

	Per Cent
Organic matter:	
Average dairy ration	45
Heavy concentrate ration	35
Coarse fibrous roughage ration	55–65
Nitrogen:	
Dairy animals	35–75
Meat animals	65–90
Work animals	85–95
Phosphorus:	
Dairy animals	50–80
Young, growing animals	35–50
Work animals ..	75–95
Potassium:	
Dairy animals	65–85
Meat animals.	75–90
Work animals	90–98

* FIPPIN, E O, "Farm Manure" Lesson 141 pp. 178 and 179 Farm Reading Course, New York State College of Agriculture, 1919

TABLE 42—APPROXIMATE COMPOSITION AND WATER-ABSORBING CAPACITY OF BEDDING MATERIALS*

Bedding material	Pounds in 100 lb. of air-dry material				
	Water retained	Organic matter	Nitrogen	Phosphoric acid	Potash
Wheat straw	220	80	0 5	0 25	0 80
Oat straw	285	80	0.6	0 30	1 20
Barley straw†	. .	..	0 6	0 20	1 10
Rye straw†	220	..	0 5	0 30	0 85
Corn stover	350	70	1.0	0 30	1 40
Peat moss	1,000	65	1.0	0 20	0 20
Muck	450	50	1 5	0 25	0 30
Dried forest leaves, oak...	200	75	1.0	0 20	0 35
Pine needles	175	80	1 0	0 20	0 15
Sawdust	435	90	0 2	0 10	0 40
Shavings, soft wood	375	90	0 1	0 10	0 30

* FIPPIN, E O, "Farm Manure," Lesson 141, pp 178 and 179, Farm Reading Course, New York State College of Agriculture, 1919

† VAN SLYKE, L L, "Fertilizers and Crop Production," pp. 478 and 484, Orange Judd Publishing Co., Inc, New York, 1932.

are generally used if available. The composition, together with the approximate water-absorbing capacity of commonly used bedding materials, is given in Table 42.

Marked differences appear in the quantity of organic matter and plant nutrients in bedding materials. The effect of these differences may be more fully appreciated if one considers that a herd of 30 cows requires about 55 tons of bedding a year, although less is often used. In the event of a choice of bedding materials, water-absorbing capacity and the amount of plant nutrients carried deserve consideration. Chopping straw increases its water-absorbing capacity, but chopped straw does not stay in place so well as the long straw. Some discrimination against sawdust and shavings from highly resinous woods apparently is justified, for these are regarded as being detrimental to some crops. If used, a lower rate of application per acre is suggested than if straws serve as bedding.

In some sections, bedding materials are scarce and expensive. Consequently, a smaller quantity, and sometimes none, is used. Under these conditions, the manure is more concentrated than if diluted with bedding. It is, moreover, difficult to handle because of the high proportion of liquid in it.

Number, Kind, and Age of Animals.—Animals vary within moderately wide limits in the extent to which they retain plant nutrients from the feeds consumed. Work animals, such as horses and mules, use carbohydrates along with some protein and other nutrients from their feed which is mainly grain and hay. Growing, young animals, milking cows, hens, and sheep retain additional nutrients from the feeds consumed by them. Some of these variations are shown in Tables 41 and 43.

The moisture contents of whole fresh manures vary from 55 per cent in hen manure to 85 per cent in pig manure. Dry matter obviously differs in exactly the opposite direction, poultry manure being three times as rich in dry matter as pig manure. A slight difference occurs in the quantities of nitrogen and potash recovered per 1,000 pounds of live weight of the different animals. The recovery of phosphorus varies widely—40 pounds a year in cow manure and 80 in hen manure from 1,000 pounds of live weight.

If the feed consumed is considered, it is evident that horses retain only small proportions of the nitrogen in their highly car-

TABLE 43.—PRODUCTION AND COMPOSITION OF THE MANURE OF FARM ANIMALS*
(Per 1,000 Pounds Live Weight)

Animal	Constituent	Annual production, pounds	Water, per cent	Dry matter, pounds	Nitrogen, pounds	Phosphoric acid, pounds	Potash, pounds
Horse..	Liquid	4,000	90	400	60	Trace	48
	Solid	14,500	70	4,350	66	44	58
	Total	18,500	74	4,750	126	50	106
Cow...	Liquid	8,000	93	560	64	Trace	80
	Solid	18,000	80	3,600	63	36	45
	Total	26,000	84	4,160	127	40	125
Pig....	Liquid	12,000	96	480	60	12	72
	Solid	18,000	78	3,960	54	45	54
	Total	30,000	85	4,440	114	57	126
Sheep..	Liquid	4,500	87	585	68	23	57
	Solid	8,500	55	3,825	68	34	43
	Total	13,000	66	4,410	136	57	100
Hen...	Total	10,000	55	4,500	130	80	90

* FIPPIN, E. O., "Farm Manure," Lesson 141, p. 175, Farm Reading Course, New York State College of Agriculture, 1919.

bonaceous feed. Cows, in contrast, consume high-protein grains in large quantities, and still only 127 pounds of nitrogen a year are recovered in 13 tons of cow manure. Hen and pig feeds are comparable in that both consume chiefly grains. The feed of the hen, however, is usually much higher in protein than is that of the fattening pig. Even though the total amount of pig manure is three times that from an equal live weight of hens, the latter actually has slightly more dry matter in it. From these data, one may see some of the variations in the manures produced by different animals.

Attention is called to the quantities of manure produced annually by 1,000 pounds of live weight of different animals. According to Table 43, dairy cows produce 13 tons of actual solid and liquid excrement a year, pigs, 15, work horses 9¼, sheep 6½, and hens 5 tons a year with no bedding included. Since a portion

TABLE 44.—COMPOSITION AND AMOUNT OF MANURE PRODUCED PER 1,000 POUNDS LIVE WEIGHT PER YEAR*

Kind of animal	Weight of excrements, pounds	Weight of bedding, pounds	Weight of total manure, pounds	Nitrogen, pounds	Phosphoric acid, pounds	Potash, pounds
Horse.....	18,000	6,000	24,000	158	61(27P)†	145(120K)†
Cow.......	27,000	3,000	30,000	171	47(21P)	148(123K)
Pig........	30,500	6,000	36,500	180	122(54P)	170(141K)
Sheep.....	12,500	7,000	19,500	154	65(29P)	175(145K)
Steer......	15,000	3,000	18,000	135	54(24P)	72(60K)
Hen.......	8,500	.....	8,500	85	68(30P)	34(28K)

* VAN SLYKE, L. L., "Fertilizers and Crop Production," p. 225, Orange Judd Publishing Co., Inc., New York, 1932.
† P, phosphorus. K, potassium.

of this is voided by cows, sheep, pigs, and hens on pasture and by horses at work or on pasture, not all of it is recovered. Smaller quantities of manure, therefore, will be available for use on the land than these figures indicate except as the total is increased by bedding. Moreover, losses in handling and storage should not be overlooked.

Based on Table 44, for each 1,000 pounds of live weight, dairy cows produce on the average about 8 tons of fresh manure, including 1 ton of bedding during a feeding period of 6 months. It is assumed that the feeding and milking are done in the barn.

TABLE 45.—PRODUCTION OF MANURE BY THE CORNELL UNIVERSITY HERD PER 1,000 POUNDS LIVE WEIGHT

	Daily amount	Annual amount
Clear excrement produced..................	75.5 lb.	13.75 tons
Excrement produced with bedding.........	85.7 lb.	15.60 tons
Organic matter consumed..................	21.1 lb.	7,700 lb.
Organic matter voided.....................	9.18 lb.	3,350 lb.
Proportion of organic matter regained......	43.3 per cent	
Nitrogen consumed........................	0.585 lb.	215 lb.
Nitrogen voided..........................	0.26 lb.	94 lb.
Proportion of nitrogen regained............	44.3 per cent	
Proportion of ash regained................	63.6 per cent	
Proportion of water in manure............	81.8 per cent	

The quantity of manure produced is correspondingly more or less than 8 tons for longer or shorter feeding periods. Table 45 gives corroborative data.

Although the data in Table 44 differ in minor details from those in Table 43, they are similar. The composition data, Table 42, are valuable in that they show the influence that bedding might have on the plant-nutrient content of manures.

In Table 45 is given the actual production of manure by the Cornell University Agricultural Experiment Station herd for a period of 7 days. By calculation, the annual production per cow is obtained. The annual production of manure was found to be very similar to that shown, from other investigations, in Tables 43 and 44.

As an average of a number of large farms both in the dairy, and in the cash-crop sections of New York, the author found the amount of manure produced to be approximately 200 tons per farm per year according to the farmers' estimates. The production is of course very much lower on grain than on the larger livestock farms.

Plant Nutrients in Manures.—The actual amounts of plant nutrients in the different animal manures are shown in Tables 43 and 44. General, or "average," composition figures are useful in everyday discussions of the utilization of manures for the fertilization of crops. The per cents and pounds of plant nutrients in 1 ton of manure are given in Table 46.

TABLE 46.—"AVERAGE" COMPOSITION OF MIXED MANURES

	Dry matter	Nitrogen	Phosphoric acid	Potash
Per cent	20–25	0.5	0.25	0.5
Pounds in a ton	400–500	10	5	10

According to these data, 1 ton of mixed manure contains a total of only 25 pounds of plant nutrients. This quantity of nutrients is carried in about 40 pounds of the more concentrated commercial fertilizers.

Urine, a Valuable Part of Manures.—A consideration of the composition of manures (Table 43) shows that on the average about one-half of the nitrogen, three-fifths of the potash, and a

FIG. 133 —Manure pile in Germany with cistern under it. This picture shows a fairly deep pile of manure with a flat top The cistern which is immediately below the pile receives the liquid from the stable and any liquid that passes through the solid manure. From the cistern the liquid is taken direct to the field.

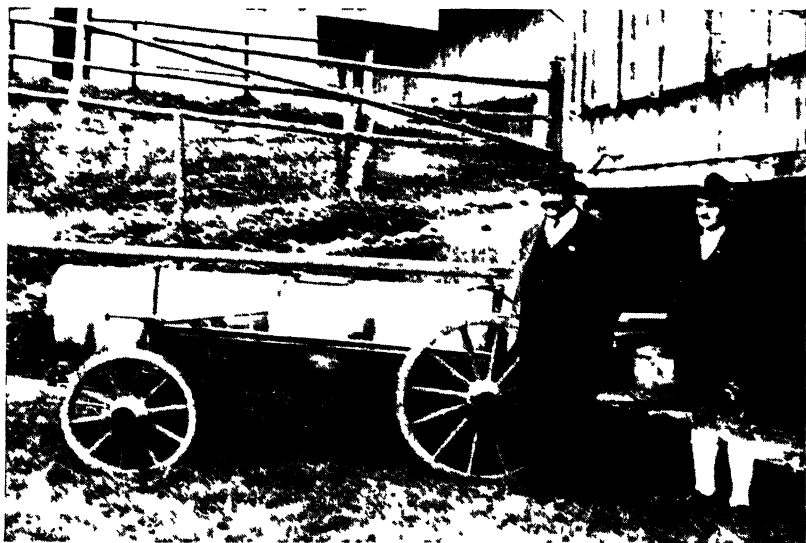



FIG. 134.—The tank wagon for liquid manure. The liquid is pumped from the cistern into the tank from which it is spread on the land.

mere trace to nearly one-fourth of the phosphorus is found in the urine. Moreover, this soluble part of the nutrients is the part that is readily available to plants and, therefore, is the most valuable from many points of view. And, being soluble, this part may be readily lost by leaching. Consequently, manure left under the eaves of the barn or piled in the open lot suffers heavy losses of both nitrogen and potash. Complete protection from rain and snow is essential for the conservation of the liquid part of manures.

In parts of Europe, the liquid manure is conducted into a cistern from which it is pumped into wagon tanks and hauled to the field (Figs. 133 and 134). From the tanks, the liquid is spread on the land. Similar methods are employed on a few farms in this country.

On most American farms, however, bedding is available, and stable floors are designed accordingly. Because a high proportion of the readily available nutrients is in the liquid part of manure, any good plan for its conservation includes the retention of *all* or as much as possible of the liquid part of it. It may be absorbed in bedding and thus incorporated with the solid portion, or the liquid may be kept separate and utilized as it is in Europe. Farmers cannot afford to lose the fertility value of the liquid manure.

Dried Manures.—In recent years, dried manures have come onto the market in quantities of increasing importance. The plant-nutrient content of dried sheep, goat, and poultry manures is given in Table 47.

TABLE 47.—COMPOSITION OF DRIED SHEEP, GOAT, AND POULTRY MANURES*

	Sheep, per cent	Goat, per cent	Poultry, per cent
Nitrogen	2.50	1.35	4.50
Phosphoric acid	1.50	1.40	3.20
Potash	1.50	3.60	1.35

* VAN SLYKE, L. L., "Fertilizers and Crop Production," p. 171, Orange Judd Publishing Co., Inc., New York, 1932.

The dried manures are much richer in nutrients than are average mixed farm manures and correspondingly higher in value ton for ton.

Properties of Manures.—Cow and swine manures naturally are *wet*, containing as they do in the mixed clear excrement about 85 per cent of water. These manures, being wet, decay slowly and remain cool. Therefore, they are often called "wet" or "cold" manures. Sheep, horse, and hen manures, in contrast, carry approximately 66, 74, and 55 per cent of water, respectively. Being drier, these manures heat up and decay quickly, even in the coldest weather. Consequently, these are designated as "dry" or "hot" manures. The rising steam from "craters" in a snow-covered pile of horse manure is a familiar part of the barnyard scene in the colder climates.

Every pound of manure is charged with literally billions of decay organisms. The work they begin in the digestive tract is continued after the manure is voided by the animal. No time is lost; their work is continuous. The composition of manure as a consequence is *ever changing*, except when it is frozen.

Manure is *variable* in composition. It varies with the animal, its feed, age, and work, and with the quantity and kind of bedding used. Exposure to rain and snow results in losses of soluble materials and changes in composition in comparison with protected manures.

Manure is a *bulky*, or dilute, fertilizing material in that it contains less of actual plant nutrients than may be carried in a small quantity of a concentrated commercial fertilizer. In fact, a fertilizer that carries 40 per cent of plant nutrients is thirty-two times as concentrated as average farm manure. Bulky and dilute are, indeed, outstanding expressions of the properties of manure.

In general, manures do not decompose and disappear from the soil completely in a single season. Some *carry-over*, or *residual*, effect is generally noted. On the heavier soil types, particularly if they are not well drained, a marked residual effect is noted. In contrast, manure produces essentially no effect after the first year on well-drained, coarse soils, such as gravelly and sandy loams and even coarse, calcareous silt loams. On a well-drained silt loam, approximately one-half the effect of the manure may be expected the first year, one-fourth the second year, and the remainder over the next 1 to 3 years. Naturally, heavy rates of application of manure result in more pronounced residual effects than do light applications. The latter, in fact, show little residual benefit after the second year.

The Decay of Manures.—The organisms previously mentioned as being present in manure at the time it is produced continue their work. In the breakdown of the carbonaceous part, carbon dioxide is produced. It is lost directly in gaseous form or is dissolved in the moisture in the manure and may be lost by leaching. Thus organic matter is lost from manures. The undigested protein and other nitrogen-carrying materials are attacked and changed to ammonia which in turn is dissolved in the moisture, forming ammonium hydroxide. The pungent odor so often noted in horse stables or coming from heaps of "hot" manures, particularly in warm weather, is produced by gaseous ammonia that is passing away into the atmosphere. In such situations, a wasteful loss of nitrogen is taking place.

Losses of Plant Nutrients.—Manure, since it is an ever-changing material, is subject to heavy losses of soluble materials when exposed to normal rainfall. Some years ago, at the Cornell University Agricultural Experiment Station, determinations were made of actual losses. Two lots of manure, one horse, the other cow manure, were piled in the open on Apr. 25 and weighed again on Sept. 22. The results are given in Table 48.

TABLE 48.—LOSSES OF ORGANIC MATTER AND NUTRIENTS DURING SUMMER STORAGE AT CORNELL*

	Number of pounds at beginning of experiment		Number of pounds at end of experiment		Percentage of loss	
	Horse	Cow†	Horse	Cow	Horse	Cow
Gross weight	4,000	10,000	1,730	5,125	57	49
Nitrogen	19.6	47	7.79	28	60	41
Phosphoric acid	14.8	32	7.79	26	47	19
Potash	36.0	48	8.65	44	76	8

* ROBERTS, I. P., The Production and Care of Farm Manures, *Cornell Univ. Agr. Exp. Sta., Bull.* 27, pp. 32, 33, 1891.

† Three hundred pounds gypsum added at beginning.

Essentially one-half of the organic matter (gross weight) and two-thirds of the value of the horse manure and one-third of the value of the cow manure disappeared during the five warm months of exposure at Ithaca, N.Y.

In tests at the New Jersey Experiment Station, manure was exposed for 2 months. It suffered a loss of 51 per cent of the nitrogen, 46 per cent of the phosphoric acid, and 52 per cent of the potash it contained when fresh. At the Ohio Experiment Station, steer manure lost 40 per cent of its organic matter in 3 months, and horse manure 57 per cent in 5 months.

On the basis of the available data, it is safe to state that mixed manure exposed during the summer in the ordinary loose pile may be expected to lose one-half to two-thirds of its organic

FIG. 135.—Wasting manure. This is a most wasteful way of handling manure. Is the management of the manure the cause of the condition of the barn?

matter, nitrogen, and potash and about two-fifths of its phosphorus (Fig. 135). Since cultivated soils have lost and are losing valuable nutrients and organic matter and since crop yields at the same time are falling, serious consideration of ways and means of avoiding these losses is definitely in order.

THE CONSERVATION OF FARM MANURES

Means of Reducing Losses from Manures.—Because of the myriads of decay organisms in fresh manure, loss of organic matter and nitrogen cannot be avoided in warm weather and in "hot" manures at any time. Many practicable means of reducing losses may be employed on nearly all farms. Among these means are spreading while fresh, protecting from the weather,

packing, and keeping the manure wet. Some slight help may be obtained by the use of preservatives.

Hauling Out and Spreading While Fresh.—In many dairy sections, the practice of hauling manure out and spreading it on the soil every day has become firmly established. On many northeastern dairy farms, hauling out the previous day's manure is as much the day's chore as feeding or milking the cows. If only a few animals are kept, the manure may well be allowed to accumulate to the extent of a full load before hauling it to the field. Whether more loss occurs on the field than in a pile in the barnyard is a question that is often raised. Fortunately, experiments in Ohio shed light on this point. Manure was hauled out and spread on the land early in January. This was called "stall" manure. The same quantity of manure was piled in the barn lot in the ordinary manner and was called "yard" manure. This manure was hauled out and spread 3 months later, about April first. The increases in yields of corn, wheat, and hay are given in Table 49.

TABLE 49.—INCREASES IN CROP YIELDS FROM "STALL" COMPARED WITH "YARD" MANURE*

Condition of manure	Corn†		Wheat		Hay
	Grain, bushels	Stover, pounds	Grain, bushels	Straw, pounds	Pounds
Stall‡	32.6	1,502	14.8	1,586	2,214
Yard	28.4	1,257	13.3	1,360	1,667
Gain for spreading in January	4.2	245	1.5	226	547

* THORNE, C. E., and staff, The Maintenance of Soil Fertility, *Ohio Agr. Exp. Sta., Bull.* 336, p. 615, 1919.

† Corn and wheat average of 21, and hay average of 18 crops.

‡ These increases are the result of comparing both "stall" and "yard" manures plus phosphorus with an untreated check plot. Each is an average of 2 plots each year.

These data are the best answer to the question of whether the loss of plant nutrients is greater when manure is spread on frozen soil than when it is left in the barn lot. Spreading in January over the 21-year period gave 4.2 bushels more corn and 1.5 bushels more wheat; as an average of 18 years, spreading in January gave 547 pounds more hay to the acre than spreading in April after 3 months' exposure.

Elsewhere, fresh manure has been shown to increase yields of feed crops by 50 to 100 per cent more than does similar manure that had been stored in the open throughout the summer months. Certainly, spreading manure for the feed crops as soon as possible after it is produced is good management of the manure.

Protection from Rain and Snow.—Under some conditions, it is not feasible, even if possible, to haul manure to the field daily. In that case a roof of some sort over the manure is required in order to avoid heavy loss of the soluble constituents. The roof need not be an expensive one. Anything that prevents leaching of the manure by rain and thawing snow is beneficial. Shutt in Canada compared mixed horse and cow manure, one lot being protected from the weather and the other exposed to it. The losses he found under these conditions are shown in Table 50.

TABLE 50.—EFFECTS OF PROTECTION AND TRAMPING ON LOSSES FROM MANURE IN STORAGE

Conditions and location	Losses, per cent			
	Organic matter	Nitrogen	Phosphoric acid	Potash
Canada:*				
Manure stored 1 year				
Protected	60	23	4	3
Unprotected	69	40	16	36
Pennsylvania:†				
Manure stored 6 months				
Protected: Tramped by young stock	..	5.7	8.5	5.5
Protected: Not tramped at all	..	34.1	14.2	19.8

* SHUTT, FRANK T., Barnyard Manure, *Canadian Dept. Agr. Central Exp. Farm, Bull.* 31, p. 19, 1898.

† FREAR, WILLIAM, Losses in Manure, *Pennsylvania Agr. Exp. Sta., Bull.* 63, p. 5, 1903.

That leaching was prevented is shown by the unusually slight loss of potash from the protected manure. Reducing the loss of nitrogen by nearly one-half is decidedly worth while. The saving of 9 per cent of the organic matter appears unimportant, but the conservation of these valuable constituents deserves attention.

That decay of organic matter in a loose pile is rapid in the presence of oxygen is well known. A comparison was made by the Pennsylvania Experiment Station to learn the effect of compacting manure and of leaving it loose. Both the loose and compacted manure piles were under cover and, therefore, protected from leaching. These figures are in the second part of Table 50.

The losses from the loose manure were somewhat larger than the losses in the Canadian comparison, but they may be accounted for by differences in climate and in the manure itself. The trampling by young stock did effectively compact the manure.

Fig. 136.—A deep pile of manure in England. It is between 5 and 6 feet in depth; no liquid was detected as having come out of the pile.

Furthermore, by excluding excessive amounts of oxygen and by keeping the manure from drying out, compacting effected a remarkable conservation of plant nutrients. Keeping manure moist in storage is always of first importance.

On many farms, the livestock run loose in open sheds or in the basements of barns. Feeding cattle, young stock, dry cows, and feeding lambs run loose in this manner. Allowing the manure to accumulate under such covers is common practice. Bedding is used as needed to keep the surface of the manure relatively dry. Trampling by the stock compacts the manure and keeps it moist throughout.

As a result of these respective measures, three vital conditions for conserving the value of the manure are fully met: (1) Leaching

is prevented. (2) Oxygen is excluded and aerobic decay of the manure is well controlled. (3) Losses of ammonia are kept at a minimum. In a cool basement barn, in particular, manure escapes severe losses of organic matter and nitrogen even during the summer months.

Next to hauling manure to the field daily, allowing it to accumulate under cover in this way is an especially good practice. Such manure is highly desirable for wheat or for top-dressing new seedings or old meadows in late summer or autumn.

Storage in a Deep Pile.—Storage in the open is sometimes resorted to as a temporary expedient. A deep pile is best, 4 to 6

FIG. 137.—An open, concrete manure pit. If preferred a roof may be built over the pit. (*Courtesy of J. A. Slipher.*)

feet deep or even more being satisfactory (Fig. 136). A pile with steep sides and the top flat or slightly depressed toward the middle is suitable. A pile of this depth compacts itself by its own weight and thereby reduces the rate of decay of the manure. The top should take in all the rain, for a high moisture content aids in retarding bacterial action. Moreover, the moisture absorbs gaseous ammonia and thus reduces the loss of nitrogen.

Storage in a Pit.—Outdoor storage in open piles should be regarded as an emergency or merely temporary expedient and not as an approved practice in a permanent agriculture. A tight-bottomed manure pit is essential for the preservation of the organic matter and nutrients in manure of which many of our

soils are greatly in need. Prevention of loss of liquids is far more important than keeping out the sun and rain. In fact, with the dry manures an open pit that receives the rain is preferable under conditions of moderate rainfall (Fig. 137). Because losses occur in the best type of pit, pits should be so built as to be relatively inexpensive.

Manure Unbalanced as Fertilizer.—The general composition of mixed manures has been given as 10 pounds of nitrogen, 5 of phosphoric acid, and 10 of potash to the ton. In contrast,

TABLE 51.—PLANT NUTRIENTS IN 1 TON OF MANURE AND OF FERTILIZER

Material	Nitrogen	Phosphoric acid	Potash
Manure	10	5	10
5-20-5 fertilizer	100	400	100

high-analysis, mixed, grain fertilizer has 100 pounds of nitrogen, 400 of phosphoric acid, and 100 of potash to the ton. This relationship is shown in Table 51.

This mixed grain fertilizer has 10 times as much nitrogen and potash and 80 times as much phosphoric acid as does average farm manure. In other words, manure is deficient in phosphorus

TABLE 52.—CROP INCREASES FROM PHOSPHORUS IN ADDITION TO FARM MANURE*
(Average for 26 Years, 1897–1923)

Wooster silt loam (8 tons manure per acre)	Crop yield, increase per acre		
	Corn, bushels	Wheat, bushels	Clover, pounds
Stall manure only	23.9	10.0	1,281
Stall manure + 320 lb. of 14 per cent superphosphate	34.3	15.1	2,196
Stall manure + 320 lb. of rock phosphate†	30.1	12.9	1,775
Gain for superphosphate over manure	10.4	5.1	915
Gain for rock phosphate over manure	6.2	2.9	494

* THORNE, C. E., and staff, The Maintenance of Soil Fertility, *Ohio Agr. Exp. Sta., Bull.* 381, p. 326, 1924.

† Rock phosphate usually carries about 30 per cent of phosphoric acid.

for grains and, in fact, for most crops. The addition of phosphorus to manure in the stable, on its way to the field, or to manured land is essential for best results from the manure.

The effect of supplementing manure with phosphorus is shown in Table 52. We are concerned here only with the benefits of using phosphorus in addition to manure on corn, wheat, and clover. The quantities of phosphorus used in the experiment on which Table 52 is based were small, that in the superphosphate being equivalent to but slightly more than 200 pounds of 20 per cent superphosphate to the acre for a rotation of 3 years. A heavier application of phosphorus may have been expected to give a greater increase as a supplement to manure.

FIG. 138.—Applying superphosphate in the dairy barn. By putting superphosphate on the manure in the barn phosphorus may be applied to the soil along with the manure, thus saving time. Moreover, superphosphated manure is of greater value than manure alone. (*Courtesy of H. R. Smalley, National Fertilizer Association.*)

Dairy cows produce about 9 tons of manure in the stable, including bedding, during a barn-feeding period of 7 months. The addition of 2 pounds a day amounts to 420 pounds of superphosphate for each cow or for the 9 tons of manure (Fig. 138). An application of 10 tons of manure to the acre on this basis puts on 467 pounds of superphosphate to the acre. For a rotation of

feed crops of 3 years, this application of phosphorus is satisfactory. Increasing the superphosphate to 2½ or 3 pounds a cow a day supplies sufficient phosphorus for a 4-year rotation of feed crops.

In the sections that use finely ground rock phosphate, this may be added to manure in the same way as superphosphate. In the open sheds or basements where stock is housed, rock phosphate may be scattered over the manure as it accumulates. For dairy cows that are housed for 6 months out of the year, 4 pounds a day adds 720 pounds of rock phosphate to approximately 8 tons of manure. This is equivalent to a total of 900 pounds of rock phosphate to the acre, on the assumption that manure is used at a rate of 10 tons to the acre. Both rates of application may be varied to suit the immediate conditions.

THE ECONOMIC UTILIZATION OF MANURES

By proper utilization, manure may be expected to yield better returns than otherwise. In the past, manure has been used lavishly and in some cases has done actual damage to certain crops. On very few farms is so much manure produced that heavy applications can be made to some fields without robbing many acres of a fair share of the supply.

Response of Crops to Manuring.—Crops vary markedly in their response to additions of manure to the soil. Manure being high in nitrogen is especially helpful to crops that produce mainly vegetative growth. In this category are included the grasses, (Fig. 139), leafy vegetables, and silage crops. These crops must have phosphorus and potash, but they do make good use of the relatively high nitrogen content of farm manures.

In the Midwest, for example, manure in light application when spread on wheat in late fall or early winter has been of great service. The manure retards freezing and thawing and holds snow, all of which tends to lessen heaving on soils subject to it. Moreover, the manure protects the plants to a fair degree from the drying effects of cold winter winds and, in addition, aids in checking soil movement by both wind and water during winter and early spring.

Manure applied on new seedings after the nurse-crop grain has been harvested is especially helpful to the young clover and grass plants. They are benefited in exactly the same manner as wheat is. In addition, the plant nutrients that are supplied

strengthen the young plants and appear to be particularly beneficial to the seedlings on unlimed, somewhat sour soils. And mature meadows, also, respond well to moderate applications of manure.

Methods of Application.—A great deal of manure, particularly on the smaller farms, is still spread with the fork by hand. It is very difficult to spread manure evenly by this laborious, time-consuming method. The mechanical manure spreader (Fig. 140)

Fig. 139.—Effect of manure on yields of hay. Twenty tons of manure was applied in six years for the hay on the left, one-half of it on the first and the remainder on the third year of timothy; no manure was used for the hay on the right. The manured soil averaged 5,704 pounds of hay to the acre; the unmanured averaged 1,950 pounds to the acre. (*Dept. of Agron., Cornell Univ. Agr. Exp. Sta.*)

shreds and spreads the manure at the same time in a superior way. The spreader not only fines the manure so that it drops into very close contact with the soil but also applies the manure evenly over the land. Spreading is done more easily, more quickly, and in every way, more satisfactorily with this implement than by hand. Few, if indeed any other, implements pay so handsomely on the investment as does the manure spreader on farms with an average production of manure (see also Fig. 141).

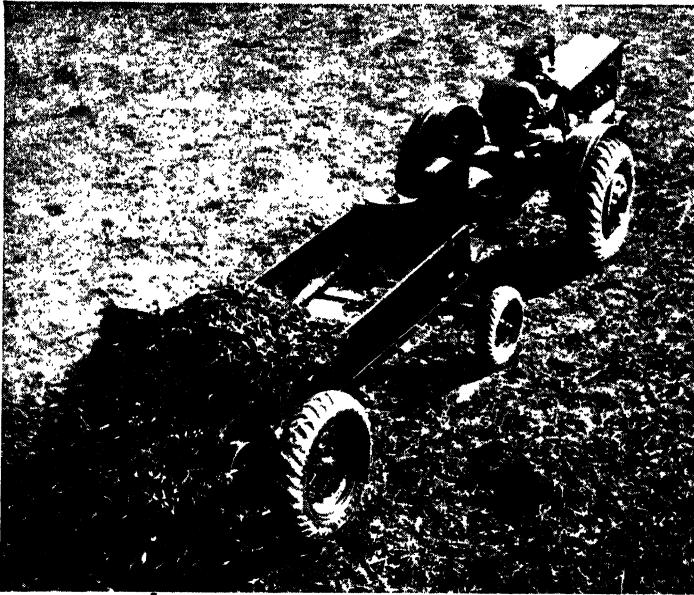



Fig. 140.—A manure spreader in action. A spreader tears up the manure in distributing it. Note how uniformly it covers the soil to the right of the spreader. (*Courtesy of the New Idea, Inc., Coldwater, Ohio.*)

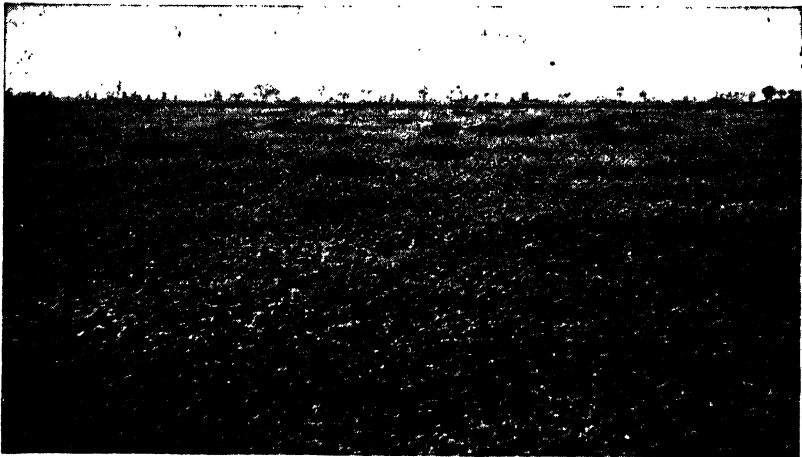



Fig. 141.—Effect of piling manure in the field. Here manure was piled the previous season and spread later. The taller buckwheat grew where the manure had been piled. Usually grain on such spots lodges before filling. The nitrogen that leached into the soil from the heaps of manure causes the lodging and some resultant loss. (*Courtesy of E. VanAlstine.*)

Time of Application.—As already pointed out, the best time for applying manure to the land is as soon as feasible after it is produced. For cultivated crops, such as corn or cabbage, manure may be applied at any time after the preceding crop has been harvested and before plowing for these crops. For most cultivated crops turning manure under is preferable to applying it on the surface.

On sandy soils, manure is sometimes applied on the surface after the crop is planted. In this position, nutrients are leached downward to the roots. If turned under on coarse soils, manure is already below the roots, and leaching soon carries the nutrients beyond their reach.

TABLE 53.—EFFECTS ON YIELDS OF DIFFERENT RATES OF APPLICATION OF MANURE*

Manure, rate of application	Potatoes (average for 30 years)		Wheat (average for 29 years)		Clover (average for 27 years)	
	Yield, bushels	Increase per ton, bushels	Yield, bushels	Increase per ton, bushels	Yield, pounds	Increase per ton, pounds
4 tons	132.7	6.00	32.2	1.50	4,186	198
8 tons	142.7	4.30	34.0	1.06	4,568	156
16 tons	170.3	3.22	34.9	0.61	5,145	103
	Increase produced per acre†					
	Bushels		Bushels		Pounds	
16 tons on 4 acres (4 tons per acre)	96.0		24.0		3,168	
16 tons on 2 acres (8 tons per acre)	68.8		16.96		2,496	
16 tons on 1 acre	51.6		9.80		1,650	

* THORNE, C. E., and staff, The Maintenance of Soil Fertility, *Ohio Agr. Exp. Sta.*, *Bull.* 381, pp. 329–330, 1924.
† Calculated by the author.

Rate of Application.—The rate of application of manure is a problem that arouses keen interest among farmers. The author's own contacts with hundreds of farmers indicate that their usual rates of applications are often uneconomically high. Experi-

mental results are of real service in solving this question. Typical effects of different rates of application are shown in Table 53.

The second part of the table is of interest in that it shows the increase in yield from 16 tons put on 1 acre, what the increase would have been if 16 tons had been applied on 2 acres at 8 tons an acre, and, further, what 16 tons would have produced as an increase if applied on 4 acres at 4 tons an acre. On the basis of the data in columns 3, 5, and 7 of Table 53, one notes that increases in yield per ton of manure diminish with the higher rates of application.

It should be borne in mind that the manure was applied for potatoes without any other fertilization. The yields appear low, and yet they are comparable. The increase from the 8-ton application is materially greater on 2 acres than that from 16 tons on 1 acre.

Similar data might be cited from Pennsylvania, Indiana, Cornell, and other experiment stations. All available data show that relatively light applications made at frequent intervals (for example, 8 tons every 4 years) give larger total returns for the manure that is ordinarily available than do heavier applications (for example, 16 tons every 8 years).

The following rates of application are suggested for average farm conditions:

Crop	Tonnage of Manure per Acre
Corn	8–10
Wheat	8–10
New seedings	8–10 or less
Pasture	8–10 or less
Timothy	8–10 or less
Potatoes (not recommended)	12–15 if used
Apples	10–12
Beans (dry)	8
Tobacco	10–20

"Artificial" Manure.—The shortage of manure on grain and vegetable farms has directed attention to the possibility of making better use of the leftover materials on many farms. Among these are the straw from small grains, corn and other stalks, cane pomace, and many other materials that lack market value under a particular set of conditions. Oat and wheat straws, for example, are not very useful as such on a grain farm on which few

animals are kept. A useful "artificial" manure can be made from these otherwise valueless materials.

In the production of manure directly from straw, the digestive work is done by fermentative organisms in the straw pile. Ordinarily, the change from feed to manure is brought about in the digestive tract of the animal, with a large measure of aid from similar organisms.

Albrecht[1] used a mixture equivalent to approximately 70 pounds of sulphate of ammonia, 20 pounds of 20 per cent superphosphate (less of 32 or 40 per cent grades), and 60 pounds of limestone to the ton of straw. The mixture was introduced into the straw during threshing. Others have used similar mixtures.

There must be nitrogen to enable the organisms to break down the highly carbonaceous straw, some additional phosphorus for the organisms, and a little limestone for preventing the development of too high a degree of acidity. Too much acidity would stop the process of decay. In areas of 35 to 40 inches of well-distributed rainfall, artificial wetting of the straw is not necessary. The process of decay requires 2 to 5 months under ordinary conditions. This so-called artificial manure has color, consistency, and value similar to that of ordinary farm manure.

The introduction of the "combine" which leaves the straw spread over the field has changed the situation somewhat. Even so, the straw may be collected for bedding, as is done on livestock farms. Under conditions of special need for artificial manure, the straw may be collected for this purpose.

Value of Farm Manures.—The question often arises as to the dollar value of manure per ton. To this, there is no one answer. On most farms, manure is worth whatever it produces in larger yields of crops. A value in dollars per ton often does not exist in the absence of a market for manure. Its value should be computed on the basis of the increases produced over a period of several rotations rather than on the increase in yield of the crop to which the manure was applied. Long-time records show that the consistent application of manure increases the nitrogen and organic content and the water-holding capacity of the soil.

[1] ALBRECHT, W. A., Artificial Manure Production on the Farm, *Missouri Agr. Exp. Sta., Bull.* 258, 1927. See also Conservation of Fertilizer Materials from Minor Sources by C. C. Fletcher, *U.S. Dept. Agr., Misc. Pub.* 136, 1932.

Stevenson, Brown, and Foreman[1] report the average value of farm manure over a 4-year rotation in Iowa as $1.97 a ton, the range being $0.97 to $3.84.[2]

Wiancko, Walker, and Mulvey[3] report the value as $2.70 a ton over the rotation on 12 experimental fields that are well distributed over Indiana. Market prices of crops vary widely over a period of years. Calculations, therefore, based on increases in yield produced by manure and on the prevailing *field* values of crops in any particular year, give the best idea of value of a ton of manure in dollars and cents. From $1 to $2 a ton may be regarded as a normal range in the value of farm manure.

Questions

1. In what respects is manure a valuable by-product of livestock farming?

2. Outline the factors that affect the composition and the quantity of manure produced on the farm.

3. Compare the value of the liquid with the solid part of the excrement.

4. What are the outstanding properties of animal manures?

5. What are the relative losses of plant nutrients from manures stored in open piles?

6. Outline a program for conserving the value of farm manures.

7. In what respects is manure unbalanced as a fertilizer, and how may it be balanced?

8. Discuss the relative response of different kinds of crops to the application of manure.

9. Indicate feasible economic rates of application of manure for various crops.

10. Outline a method for the making of "artificial" manure.

[1] Stevenson, W. H., P. E. Brown, and L. W. Foreman, The Economic Value of Farm Manure as a Fertilizer on Iowa Soils, *Iowa Agr. Exp. Sta., Bull.* 236, 1926.

[2] Crop values used in the computations were those published in the Iowa Yearbook of Agriculture for 1922, a 10-year average covering the period 1913 to 1922.

[3] Wiancko, A. T., G. P. Walker, and R. R. Mulvey, Manure Increases Farm Income, *Indiana Agr. Exp. Sta. Bull.* 398, 1935. The crop values used were corn $0.55, oats $0.35, and soybeans $0.90 a bushel and hay $8 a ton. Stover and straw were not evaluated.

CHAPTER XIV

THE PRODUCTION AND UTILIZATION OF GREEN-MANURE CROPS

Farmers appreciate the value of animal manures, and many of them recognize almost equally well the beneficial effects that accompany the turning under directly of organic matter in the fresh, green state. With the increase in the number of tractors in use and the corresponding decrease in the number of horses and mules on farms, the supply of farm manure is definitely on the decline. Many vegetable and fruit growers, who formerly used large numbers of horses and mules, have completely mechanized their farms. As a consequence, these farms have little manure for the intensively cropped land. On dairy or other livestock farms, however, the decline in the production of manure is not so marked.

Under these conditions, organic matter may be grown on the land and, in fact, must be grown and returned to the soil unless a more or less rapid decline in productivity is to be permitted.

Crops that are grown in order that they may be turned under green for the purpose of restoring organic matter to the soil are called *green manures* or *green-manure*[1] crops. In contrast, crops that are grown mainly for the purpose of protecting the soil during late fall, winter, and early spring are referred to as *cover crops.* Crops are so used in orchards and vineyards and on vegetable soils. Such crops when turned under, however, do add highly desirable organic matter to the soil. A distinct line, therefore, between cover and green-manure crops does not always exist.

Green-manure crops can be used to excellent advantage in the South and Southeast and in many humid areas that have long growing seasons (Fig. 142). In the South, for example, the season

[1] Additional information on green manuring is given by C. V. Piper and A. J. Pieters, in Green Manuring, *U.S. Dept. Agr., Farmers' Bull.* 1250, 1922; see also A. J. Pieters, "Green Manuring," John Wiley & Sons, Inc., New York, 1927.

is long enough for the production of the main crops such as cotton, vegetables, tobacco, potatoes, corn, sweet potatoes, and others and for growing a green-manure crop on the land the same year.

Legumes or legumes in mixture with nonlegumes, such as grains, serve well as green-manure crops where they can be used. Biennial legumes, such as red and sweet clover, are preferable to the annual ones if the former can be used to advantage. It is notable that thoroughly inoculated biennial legumes often make more growth and fix more nitrogen in a season than do the

FIG. 142.—Rye and vetch. This mixture of rye and vetch is at a suitable stage for plowing under as green manure.

annuals. In fact, some of the annual legumes fix only small quantities of nitrogen during their short period of active growth.

Beneficial Effects of Green Manures.—If green-manure crops are grown on land that is devoted to the production of vegetables and other heavily fertilized crops, the conservation of the left-over nutrients against leaching away during the fall, winter, and spring may be of greater importance than the fixation of nitrogen directly by legumes. On less extensively cropped land, however, to which little nitrogen is ordinarily applied, its fixation by legumes, even in moderate amounts, may be of real consequence.

There is one point in favor of using legumes generally in green-manure crop seed mixtures that is worthy of consideration.

Owing to its high nitrogen content, leguminous organic matter in the soil appears to stimulate in a highly desirable way the process of decay and the liberation of nutrients for crops. If this stimulation is as important as it frequently appears to be, it alone justifies the inclusion of legumes in green-manure crop seed mixtures under many conditions (Fig. 143). Even nonlegumes, however, in the green state contain sufficient nitrogen to decay with surprising rapidity. After all, the important consideration

Fig. 143.—Canada field peas and barley. A mixture of peas and barley or oats constitutes a good mixture for a late spring green-manure crop. This mixture serves well over a considerable range of latitude.

often is the return of organic matter to the soil, whether it be leguminous or nonleguminous in character.

On Crops.—In South Carolina at the Pee Dee substation, Hall, Albert, and Watson report the results of 5 years' work with Austrian winter peas and vetches. These crops were planted between the cotton rows early in September with a one-horse grain drill. The data on yield were taken about the same time each year. The amounts of dry matter and of nitrogen obtained are given in Table 54.

It may be noted that, although each of these legumes produced a goodly quantity of both organic matter and nitrogen, the monantha vetch was superior to all of the others in this trial.

TABLE 54.—YIELDS OF DRY MATTER AND NITROGEN IN TOP GROWTH OF VARIOUS LEGUMES, 1929–1933*
(5-Year Average)

Crop	Dry matter to the acre, pounds	Nitrogen to the acre, pounds
Austrian winter peas	1,860	56
Monantha vetch	2,733	91
Hairy vetch	2,129†	69
Hungarian vetch	1,787	52

* HALL, E. C., W. B. ALBERT, and S. J. WATSON, Winter Cover Crop Experiments at the Pee Dee Experiment Station, *South Carolina Agr. Exp. Sta., Circ.* 51, p. 12, 1933.
† Poor seed gave a low yield in 1932.

Cotton following hairy vetch, however, produced a larger yield than it did following the monantha vetch, the Austrian peas, or the Hungarian vetch.

Alexander reports the effects of legumes and rye on the yields of cotton and corn in Georgia. His data are given in Table 55.

TABLE 55.—YIELDS OF COTTON AND CORN FOLLOWING LEGUMES AND RYE IN GEORGIA*
(7-year Average)

Green-manure crops	Seed cotton per acre, pounds		Corn per acre, bushels	
	0-9-5 fertilizer	3-9-5 fertilizer	0-10-4 fertilizer	2-10-4 fertilizer
Austrian winter peas	1,233	1,199	57.1	52.7
Monantha vetch	1,064	1,305	48.0	50.3
Hairy vetch	961	1,215	46.9	50.4
Rye	956	1,167	34.1	38.4
None	690	913	37.9	39.7

* ALEXANDER, E. D., Austrian Winter Peas and the Vetches, *Georgia Agr. Ext., Bull.* 453, p. 4, 1935.

He found that the soil growing Austrian winter peas produced the highest yields of both cotton and corn when no nitrogen was used in the fertilizer. With 3 per cent of nitrogen in the fertilizer, monantha vetch exceeded by 72 pounds the yield of seed cotton following the peas without added nitrogen. Rye grown alone

appeared to depress the yield of corn both with and without nitrogen in the fertilizer used. This depressing effect of rye may have resulted from its tying up the available nitrogen during a critical period in the growth of the corn crop. The rye, however, increased the yields of seed cotton.

Wolfe and Kipps reported yields of corn following the harvesting, as compared with the turning under of crimson clover, vetch, and rye. These data appear in Table 56.

TABLE 56.—THE EFFECTS OF TURNING UNDER CRIMSON CLOVER AND VETCH AND RYE ON THE AVERAGE YIELD PER ACRE AND PERCENTAGE OF MARKETABLE GRAIN*
(8-year Average)

Treatment	Yield, bushels	Marketable corn	
		Per cent	Bushels
Crimson clover and vetch cut for hay......	41.19	84.30	34.7†
Crimson clover and vetch turned under....	45.90	87.53	40.2
Check—no cover crop....................	30.74	78.06	24.0
Rye turned under........................	24.07	67.24	16.2
Rye cut off..............................	26.07	73.37	19.1

* WOLFE, T. K., and M. S. KIPPS, The Effect of Rotation, Fertilizers, Lime, and Organic Matter on the Production of Corn, Wheat, and Hay, *Virginia Agr. Exp. Sta., Bull.* 253, p. 45, 1927.
† Calculated by the author.

Two points of importance in these data stand out. Rye decreased not only the total yield, but also the percentage and yield of marketable corn. In contrast, crimson clover and vetch (mixed) when cut for hay increased the yield over the check one-third and the marketable corn by one-tenth. This mixture of legumes, when turned under, produced an increase in yield of 50 per cent; and seven-eighths of the corn was marketable. This was the highest quality of corn produced in the experiment.

In the same publication, Wolfe and Kipps reported on the effects of soybeans and buckwheat on yields of wheat. Soybeans when turned under increased the yield 50 per cent and nearly half as much when cut for hay. In contrast, buckwheat, a non-legume, reduced the yield when cut and taken off and increased it by only one-fifth when the entire growth was returned to the soil.

Although these data are suggestive, they are insufficient to establish many points. The general and highly beneficial effects of the leguminous crops are notable under the conditions of these trials. But it should be remembered that they were conducted in southeastern states that have a relatively long growing season.

Work carried on by the Cornell University Agricultural Experiment Station on Long Island is as yet not wholly conclusive. Here, relatively heavy fertilization of potatoes and other vegetable crops is the general practice. Returns usually warrant moderately heavy usage of nitrogen in the fertilizer applied. The production of organic matter and the conservation of plant nutrients from the fertilizer applied to the regular crop appear to be more important than the fixation of nitrogen by legumes in the green-manure or cover crops. Rye stands out as the most useful of the green-manure crops that were compared in the work on Long Island.

On Soils.—The effect on the soil of turning under green manures is that of the addition of organic matter. Complete decay of green organic matter takes place quickly in moist warm soils. The resulting humus has the desirable effects on the soil that are outlined in Chap. IV.

Possible Harmful Effects of Green Manures.—An occasional, exceptionally heavy return of organic matter to the soil in the form of green manure might be harmful under unfavorable conditions. For green manuring to be most beneficial, it is desirable that the crop be turned under in a relatively immature condition. Rye, for example, gives best results if turned under at, or preferably before, the time it heads out. When mature and beginning to "turn" or ripen, the straw is stiff and holds the soil in a loose condition. In this state, the rye may lead to severe loss of soil moisture that may retard or sometimes greatly delay the germination of the crop. In addition, the rye in the later stages of growth takes moisture that may be badly needed by the crop that follows. Moreover, in this condition the rye decays very slowly because it is so high in carbon in relation to its content of nitrogen. In order to bring about decomposition of the rye under these conditions, the decay organisms must take nitrogen from the soil. The crop, being unable to compete successfully with the soil organisms for the available nitrogen in the soil, suffers from a shortage of this essential nutrient. In a few weeks, how-

ever, if the organisms obtained sufficient nitrogen and moisture, the process of decay of the rye is completed and nitrogen again becomes available to the crop. This period of nitrogen shortage at an important stage of growth, however, delays maturity and may actually reduce the yield of the main crop. Sometimes both effects occur. When the green-manure crop is turned under in an immature, succulent condition, beneficial effects generally follow, particularly if ample nitrogen is applied for the main crop.

FIG. 144.—Vetch responds to phosphorus. The vetch on the left which received superphosphate at the rate of 400 pounds to the acre, produced four times as much material as the untreated vetch on the right. If the principle crop is heavily fertilized, however, not much benefit is expected from additional fertilization of the green-manure crop. (*Courtesy of H. R. Smalley, photographed at the Alabama Agr. Exp. Sta.*)

Requirements for Green-manure Crops.—In general, only small expenditures have been made for green manures. On comparatively small acreages of high-return crops such as vegetables, certain fruits, and, perhaps, nursery stock, however, much has been done to produce the desired green organic material for return to the soil.

Some attention to acidity is needed for sensitive crops such as alfalfa, sweet clover, soybeans, barley, red clover, and perhaps some other legumes as well. Before liming for the green manure,

however, the needs of the main crop for, or its tolerance of, lime must have full consideration. When grown after heavily fertilized crops, green manures may usually be expected to do well on the residual effects of the fertilization of the main crop. If but moderate quantities of fertilizer are used, some addition of complete fertilizer, or at least of nitrogen, may be made to advantage. Legumes may pay handsomely for phosphorus (Fig. 144). Expenditures for the green-manure crop are always gauged in large measure on the returns that may be expected from the main crop.

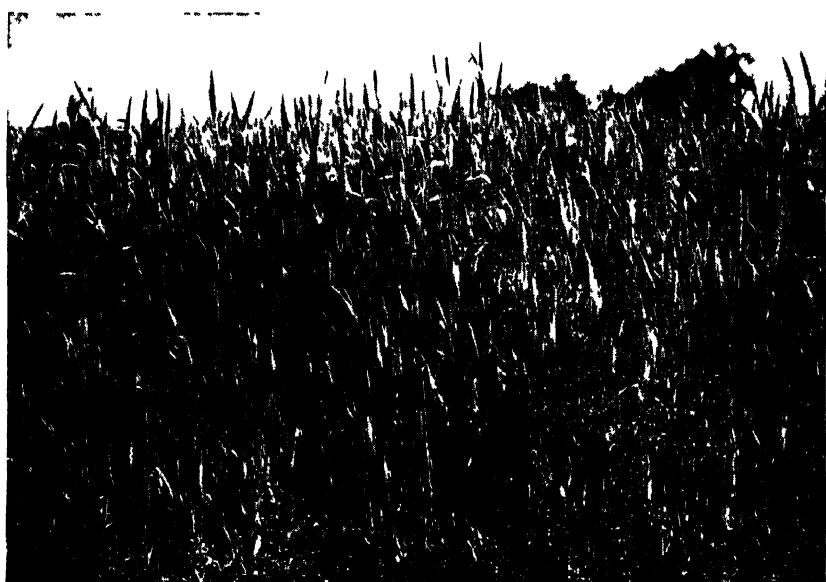



Fig. 145.—Wheat. This wheat has not headed out yet and is ready to plow under. Rye is more generally used than wheat, but under favorable conditions with respect to drainage and plant nutrients wheat may produce more material for turning under than rye does.

Useful Green-manure Crops.—Many crops are of distinct value for turning under in the green state or for use as green-manure crops. Generally speaking, the more desirable green-manure crops are those of which a plentiful supply of seed is available at a reasonable outlay for the quantity required per acre. Moreover, the crops that are not exacting in their requirements as to soil, nutrients, and general conditions are useful over wide areas. Crops that produce large quantities of organic matter are of greatest benefit to succeeding crops. Usually, crops

capable of good growth during the cool part of the growing season are most useful, for the regular crop often has been harvested and is off the land at this season.

As pointed out at the beginning of this chapter, legumes, because of their ability to fix nitrogen, have many advantages over nonleguminous plants. A compensating disadvantage of legumes, however, is the normally higher cost of the seed as compared with that of nonlegumes (Fig. 145).

A crop that is to be of real service as green manure must be capable of producing goodly quantities of organic matter under the conditions in which it is grown and during the part of the season that is available for its growth. Some crops are adapted to the cool part of the season, and others make good growth only during the warmer months.

CROPS USEFUL FOR GREEN-MANURING PURPOSES

For the Cooler Part of the Year

Name	Section
Legumes	
Austrian winter pea	South, generally
Hairy vetch	Wide north-south range
Smooth vetch	South, generally
Woolly-pod vetch	South, generally
Crimson clover	South, northern part
Monantha vetch	South, southern part
Tangier pea	South, southern part
Southern bur clover	South, southern part
Tifton bur clover	South, southern part
Nonlegumes	
Rye	Over a wide territory
Wheat	North and southward
Winter oats and barley	South and somewhat northward
Rye grass	Wide range
Summer	
Legumes	
Alfalfa	In western orchards
Red clover	Wide range, north
Sweet clover	Wide range
Cowpea	South and southern Midwest
Soybeans	Wide range
Common Sesbania	Southwest
Lespedeza	South to southern Midwest
Crotalaria	Lower south
Florida beggarweed	Lower south
Deering velvet bean	South
Canada field pea (spring)	Wide range

Nonlegumes

Name	Section
Oats, barley	Wide range
Spring wheat	Wide range
Sudan grass	Wide range
Millets	Wide range
Pearl millet	Wide range
Buckwheat	Wide range
Rape (fall)	Wide range
Corn	Wide range
Cowhorn turnip	Wide range

The plants in the preceding list are widely used for green-manure and cover crops. Owing to variations in soils, climate, and costs of establishing green-manure crops, specific recommendations cannot be made for any large area. Rye is, perhaps, more widely used than any other one crop. Millets, however, if allowed to ripen seed before being plowed under, may become troublesome as weeds in clean-cultivated crops.

For cover-crop purposes in orchards, rye, buckwheat, grasses, lespedeza, and sweet clover may be allowed to seed and may be more or less depended on to come up and cover the soil, under favorable conditions, without reseeding. Wherever feasible, this is desirable since is lessens costs of protecting the soil and of producing crops.

Rates of Seeding.—The small grains are seeded at the rate sown for grain, or somewhat heavier. Rye and fall wheat, for example, are sown at the rate of 6 to 8 pecks to the acre; oats and barley mixed, 8 to 10 pecks, varying somewhat with the size of the seed of different varieties. Wherever hairy vetch is used in a mixture with wheat or rye, 2 pecks of vetch may be sown with 4 to 6 pecks of rye or winter wheat. For many of the other crops mentioned for green manuring, seeding rates similar to those used for forage purposes, or slightly heavier, should give good yields of organic matter. If very small-seeded crops are grown for short periods only, it is obvious that considerably heavier than normal rates of seeding are essential for the production of large quantities of green organic matter.

The Place of Green-manure Crops.—Green-manure crops have usually been dovetailed in between the money crops of a single season or over a period of years. If the main crop, for example

tomatoes, requires high temperatures, both ends of the season may be used for green-manure production. Rye and vetch are then suitable over large areas. With such early crops as spinach and early lettuce, little spring growth of the green-manure crop can be obtained. Vetch would not be sown with rye then, for it could not make enough growth to warrant the expense. Fall growth alone of the rye would have to suffice unless conditions made possible the seeding of a green-manure crop earlier than rye. Ordinary oats and barley that are winterkilled could be used in this situation, for these grains are capable of good growth up to the time of the first freeze. Summer green-manure crops may be grown after the earliest spring vegetables.

With the increasing shortage of manure, it is becoming necessary in many situations to take an occasional entire season for the production of organic matter. Under these conditions, a wider selection of suitable crops is available. And often two crops may be grown and turned under during a single season. It may well be borne in mind, however, that a high level of organic matter or large applications at one time are expensive. Smaller and more frequent applications of organic matter are likely to prove more profitable over the long term than heavy applications made at long intervals.

Utilization of Green Manures.—Practical considerations direct attention to the use of green manures. Green material, particularly the leguminous, decays readily in warm soils. Green sweet clover, for example, decays and disappears as such in 10 days to 2 weeks under very favorable soil and temperature conditions. The grains ordinarily should be plowed under by the time of heading out or earlier. After rye is fully headed out, it has depleted the soil of moisture, is stiff, and holds the soil loose so that it dries out; in addition, the rye does not decay quickly. At that stage, nitrogen is needed to help bring about relatively quick decay, lest the organisms tie up the soil nitrogen to the detriment of the principal crop.

When it is necessary to seed the main crop before the green-manure crop has made much growth, a compromise may be necessary. Under these conditions, the green material is so immature and succulent as to decay very quickly. It may, therefore, be allowed to grow to within 1 week of the seeding of

some of the principal crops. Rolling will usually be necessary to produce a desirable seedbed for the main crop, except, perhaps, in the case of potatoes.

Questions

1. What is meant by green manures?

2. Can you distinguish between green-manure and cover crops?

3. Outline the beneficial effects of green manures on crops and soils.

4. Under what conditions may green manures produce harmful effects on the crop grown immediately after they are plowed under?

5. What are the more useful green-manure crops in your locality?

6. What rates of seeding of these crops should be used under different conditions?

7. Show the economic place that green manuring might occupy in the production of cash and feed crops in your section.

CHAPTER XV

FERTILIZER MATERIALS AND THEIR EFFECTS ON SOILS AND CROPS

A wide range of materials has been used for many years for supplementing the nutrients that crops can obtain from the soil. In the early days ashes, fish, or slaughterhouse waste products were used. In some cases, these materials were spread on the soil in order to get rid of them. The beneficial effects on crops, however, were noted by farmers who later purchased and used certain of these products because of the marked increases in yields produced. These materials, therefore, may be considered as being *fertilizer* materials and their use as constituting *fertilization* of crops.

In the slaughterhouse wastes, the nitrogen was the most effective fertilizer element. And, as would be expected, the nitrogen produced a marked increase in the vegetative growth of crops. Later, the inclusion or the addition of the refuse bones, because they supplied phosphorus, balanced the nitrogen and increased the production of the seed of crops such as the grain of the cereals.

In time, methods of making superphosphate from bones were worked out and guano, nitrate of soda, potash, and rock phosphate deposits were discovered. These discoveries greatly increased the range of materials available to the farmer, florist, and market gardener for application to their crops.

Many materials from widespread sources supply the three principal plant nutrients. One group supplies nitrogen, another phosphorus, and a third potassium or potash.

CARRIERS OF NITROGEN

The carriers of nitrogen are more or less generally referred to under the early term *ammoniates*. A wide range of ammoniates is found on the present-day fertilizer market. These vary from dilute to very concentrated products. Two large groups are

generally recognized, those from plant and animal sources being termed *organic* and those from mineral sources, *inorganic* materials. A relatively new group, the *synthetic*, or *manufactured*, products, may properly be added. This group, however, is divided between the organic and inorganic groups.

Organic Nitrogen Materials.—Organic carriers of nitrogen have been used over a longer period than the inorganic ones. The organics may be divided roughly into two groups, one from animal and the other from plant sources. Some of them, however, consist of mixtures of plant and animal materials. Generally speaking, the organic materials are of low analyses, or low concentration, particularly in comparison with some of the more recently introduced manufactured ammoniates.

The organic ammoniates in the dry condition have the power of absorbing considerable amounts of water and still being relatively dry. These materials, therefore, are of real service in mixed fertilizers in helping to prevent hardening or lumping. From this standpoint, organic ammoniates are referred to as *driers* or *conditioners*. The organic ammoniates possess additional value in that they contain varying quantities of the so-called *trace* elements (page 335).

Animal Ammoniates.—The more important animal ammoniates are guano, dried blood, tankage, fish meal, and sewage sludge.

Guano consists of the dead bodies of birds, bats, and seals and their droppings that have accumulated in very arid regions and in caves. Large deposits occur on the islands off the coast of Peru. Peruvian guano, the use of which dates from 1824, is the oldest commercial fertilizer used in this country. Guano carries approximately 10.5 per cent of nitrogen[1] and 10 per cent of phosphoric acid.

Dried blood is a by-product of the meat-packing industry. The good-quality blood is now used in industry and in feeds. Only the poorer grade, or blood that includes many impurities, is now available for fertilizer use. This dried blood carries about 12 per cent of nitrogen.

Tankages are on the market as *animal*, *fish*, and *garbage* tankage.

Animal tankage contains 5 to 10 per cent of nitrogen and appreciable quantities of phosphoric acid. It consists of refuse

[1] The composition of the more important fertilizer materials is given in Table 57.

materials from slaughterhouses. Meat, blood, and bone may be included, and the quality of animal tankage depends in a measure on its proportion of these materials.

Fish meal, or tankage, contains 6.5 to 10 per cent of nitrogen and 4 to 8 per cent of phosphoric acid. The material may or may not have been treated for the removal of the oil. "Acid fish" has been treated with sulphuric acid for preventing its decomposition. Acid fish carries 4 to 6.5 per cent of nitrogen and 3 to 6 per cent of phosphoric acid.

Garbage tankage is a material of low availability that has 2.5 to 3.3 per cent of nitrogen and small percentages of phosphoric acid and potash. Being made from city garbage, it contains both animal and plant materials. It is suitable for use primarily as drier or conditioner in mixed fertilizers.

Vegetable Ammoniates.—The principal vegetable ammoniates are cottonseed, castor, and linseed meals and cocoa cake and tobacco stems. All these products serve well as conditioners and contain appreciable quantities of both phosphoric acid and potash as well as nitrogen and the trace elements. The detailed figures are given in Table 57.

Cottonseed meal, the pulp from which the oil has been removed, carries 6 to 9 per cent of nitrogen. Linseed meal contains about 5 per cent and castor meal, or pomace, 4.5 to 6.5 per cent of nitrogen. Cocoa cake contains 3.5 to 4.5 per cent and cocoa-shell meal about 2.5 per cent of nitrogen.

Tobacco stems consist of the stems and waste from the manufacture of tobacco products. The nicotine may be removed for the manufacture of Black-Leaf Forty, an insecticide. Tobacco stems carry 1.2 to 3.3 per cent of nitrogen and 4 to 9 per cent of potash.

Peat and muck may be used to advantage as conditioners. They contain 1 to 3 per cent of nitrogen that is not readily available to plants.

Inorganic Ammoniates.—The two most important inorganic ammoniates are nitrate of soda and sulphate of ammonia. In addition, nitrate of potash and nitrate of soda-potash are used in small quantities.

Nitrate of Soda.—Nitrate of soda carries about 16 per cent of nitrogen. It is a standard nitrogen-carrying fertilizer material, having been first imported about 1830. Natural nitrate of soda occurs as the chief ingredient of value in the extensive mineralized

deposits, called *caliche*, that are found on the west coast of South America, mainly in Chile. The nitrate of soda is dissolved out of *caliche*, evaporated, dried, and bagged for market.

Nitrate salts, such as nitrate of soda, take up water readily from moist air and are said to be *deliquescent;* in order to avoid lumping, therefore, they must be stored in a dry place. One reason for the popularity of nitrate of soda is that its nitrogen is available to crops as soon as it is dissolved in the soil moisture. Nitrate of soda has been used in large quantities in this country in the past. Other carriers are being produced at lower cost per pound of actual nitrogen and have, consequently, displaced nitrate of soda to a considerable extent. The residual effect of nitrate of soda is distinctly alkaline. Though its long-continued use in heavy applications tends to reduce acidity in acid soils and to increase the alkalinity of alkaline soils, the quantities of nitrate of soda normally used need not be expected to produce seriously detrimental effects.

It has been claimed that Chilean nitrate of soda carries impurities that have distinct value to crops. With the present degree of purity of the Chilean nitrate, it would seem that there is less basis for this claim than formerly. At any rate, it is difficult to evaluate any difference that may exist in productive power between the Chilean and the synthetic nitrates.

Nitrate of Potash.—Nitrate of potash has 12 to 14 per cent of nitrogen and 44 to 46 per cent of potash. Although found in deposits throughout the world, nitrate of potash is not a constituent of the European potash beds. This fertilizer may be made by combining nitric acid and caustic potash.

Sulphate of Ammonia.—Sulphate of ammonia carries about 20.5 per cent of nitrogen. It is a by-product of the manufacture of coke and of so-called "illuminating" gas, widely used as fuel for cooking and for heating homes. The ammonia is recovered by passing the gas through a solution of sulphuric acid with which it unites to form sulphate of ammonia. Upon evaporation, sulphate of ammonia is obtained as grayish-colored crystals. This product is in good physical condition for distribution as fertilizer. Sulphate of ammonia is much less deliquescent than are the nitrates, and under many circumstances this is a distinct advantage in its favor. Its nitrogen occurs in the form of ammonia and may be used as such by some plants. Ammonia is readily

changed to the nitrate form in warm, moist soils by soil organisms and in this form is used by plants generally. The residual effect of sulphate of ammonia is distinctly acid, particularly if used in relatively large quantities or year after year on the same soil.

Synthetic, or Manufactured, Ammoniates.—The nitrogen in the so-called "synthetic" ammoniates is combined with other elements by chemical processes. Once nitrogen has been fixed, it may be combined chemically with other products. Among the more important synthetic ammoniates are calcium cyanamide, urea, sulphate of ammonia, and nitrate of soda. Some of these products serve as the basis for other fertilizer materials.

Calcium Cyanamide.—Calcium cyanamide as used for fertilizer has about 22 per cent of nitrogen. The pure product, however, carries 35 per cent of nitrogen. The presence of carbon gives cyanamide its dark color and its value as a drier or conditioner. Cyanamide, if used in any considerable quantity, is best applied about 10 days before the crop is planted. This allows sufficient time for the soil organisms to bring about desirable changes in it. Any contact between the seed and cyanamide reduces germination. Only about 50 or 60 pounds of cyanamide to the ton of mixed fertilizer is ordinarily used. Calcium cyanamide contains calcium in such forms and amounts that a ton is approximately equivalent in neutralizing power to 1260 pounds of good finely ground limestone. Its content of lime requires consideration in planning for its use either directly or in mixed fertilizers. The cost of nitrogen is relatively low in cyanamide.

Urea.—Urea, which contains 46 per cent of nitrogen, has the highest percentage of this element of any of the ammoniates in use today. It is a white granular or crystalline material. Its nitrogen readily becomes available to crops in moist, warm soils. Because of its deliquescence, urea has not been widely used as a fertilizer or in mixtures.

Uramon.—Uramon carries 42 per cent of nitrogen. It is urea to which a dark coating for the granules has been added. Uramon, therefore, from the fertilizer standpoint is very similar to urea but has superior physical properties.

Uramon, urea, and cyanamide are classified as "nonproteid organic compounds" by the American Association of Official Agricultural Chemists. All are desirable sources of nitrogen. Uramon may be used safely in large amounts to the acre.

Sulphate of Ammonia, Nitrate of Soda.—Sulphate of ammonia and nitrate of soda that are made synthetically are, for all practical purposes, essentially identical with the products described under Inorganic Ammoniates.

Other Manufactured Ammoniates.—The standard ammoniates serve as the basis for products that are on the market under various trade names.

Calcium nitrate, 15 per cent of nitrogen, is similar and, possibly owing to its calcium content, under some conditions preferable to nitrate of soda. Calcium nitrate, however, is more deliquescent than nitrate of soda. *Calurea,* a mixture of calcium nitrate and urea, carries about 34 per cent of nitrogen.

Ammonium nitrate is made by combining ammonia and nitric acid. About half of the nitrogen is in the ammoniacal form and the rest in the nitrate form. It carries 35 per cent of nitrogen and is deliquescent. It is made primarily for use in explosives (see also Ammoniated Superphosphate, page 328).

CARRIERS OF PHOSPHORUS

Carriers of phosphorus are referred to under the general term *phosphates.* In the fertilizer industry, instead of phosphorus, P, the term *phosphoric acid,* P_2O_5, is used. The correct name is "phosphorus pentoxide," but phosphoric acid has become firmly established. Obviously, the percentage of phosphoric acid, P_2O_5, in a fertilizing material is higher (in fact, 2.29 times higher) than that of phosphorus, P.

Carriers of phosphorus may be classified as: *natural; processed,* or *treated;* and *by-product* phosphates.

Natural Phosphates.—Natural phosphates include bones and rock phosphate.

Bone.—Bone, which is a valuable carrier of phosphorus, was the earliest phosphatic fertilizer material used. Bones accumulate largely as a waste material in meat-packing plants and as one of the products of rendering plants. Bones are used as *raw* and *steamed* bone meal.

Raw bone meal consists of bones that are ground in their natural condition, including any attached fat or glue. This product carries 20 to 25 per cent of phosphoric acid and 2 to 4 per cent of nitrogen. Steamed bone results from the boiling of bones under steam pressure, the fat and some other materials being

removed during this process. The bones are then ground and marketed as steamed bone meal. This product contains 23 to 30 per cent of phosphoric acid and 1 to 2 per cent of nitrogen. Because of the removal of the fat and other materials, the bone is porous and its phosphorus is more readily available to plants than that in the raw product.

Rock Phosphate.—In the United States, rock phosphate was first discovered in South Carolina and then in Florida and Tennessee (Fig. 146). Much larger deposits than the ones east of the Mississippi River are found in Idaho, Utah, Montana, and Wyoming. An idea of the magnitude of the western deposits may be

FIG. 146.—Rock phosphate plant in Tennessee. Here is shown the loading of the phosphate rock into cars ready for grinding. Large deposits are located in Tennessee. (*Courtesy of Ruhm Phosphate and Chemical Co., Mt. Pleasant, Tenn.*)

gained from the fact that a single township in the West is reported as having nearly 300 million tons of phosphate rock. In comparison, only 39 million tons had been mined in the whole United States up to 1913. Four million tons of rock phosphate were mined in 1937. Our total supply of phosphate rock fortunately is very large. Important foreign deposits occur in North Africa. Rock phosphate as marketed, is the finely ground, natural, untreated phosphate rock. For direct application to the soil, much of it should pass through a sieve with 300 meshes to the linear inch. Though rock phosphate is regarded as "unavailable" by fertilizer chemists, crops, particularly legumes, do obtain phosphorus from it. In acid soils or turned under with green organic matter or farm manure, a fairly good supply of phos-

phorus becomes available to crops. Its low price in comparison with that of processed phosphates enables the farmer to make a relatively heavy application so that, when it is well mixed with the soil, crop roots establish actual contact with it and extract enough phosphorus to satisfy a large part of their needs. The Tennessee rock, which is used in its raw, untreated condition, contains 30 to 32 per cent of phosphoric acid (13.1 to 14 per cent

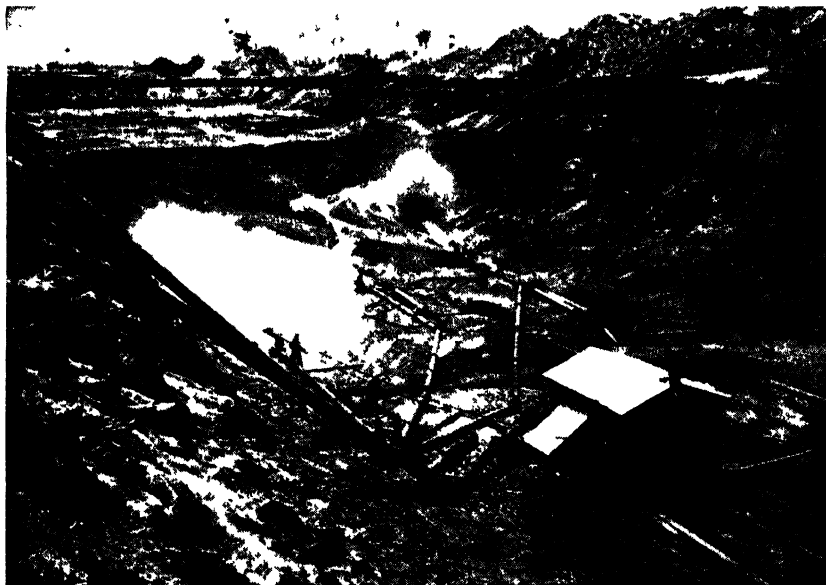



FIG. 147.—Mining Florida pebble phosphate. Water under high pressure is applied to the "pebble" and washes it into the sump at the left. From there it is pumped to the cleaning and separating plant. After thorough cleaning the pebble is ground in preparation for the manufacture of superphosphate. (*Courtesy of the American Agricultural Chemical Co.*)

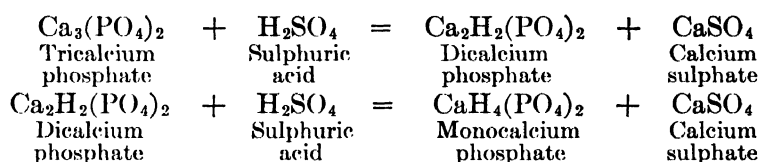
of phosphorus). In addition to phosphorus, rock phosphate carries calcium and probably other elements that are of value to crops.

Processed Phosphates.—Processed, or treated, phosphates include superphosphate (formerly called "acid phosphate") and ammoniated superphosphate.

Superphosphate.—A large share of the phosphorus used in fertilizers is in the form of superphosphate. Present-day superphosphates carry 16 to 45 per cent of phosphoric acid (7 to 19.7 per cent phosphorus). About 4 million tons of superphosphate

that carries 16 to 20 per cent of phosphoric acid is made annually[1] by mixing about 1,100 pounds of ground phosphate rock (mostly ground Florida pebble Fig. 147) with 900 pounds of sulphuric acid. This mixture makes about 1 ton of the finished product. Great care is taken by the manufacturers to be sure that superphosphate shall possess good drilling qualities when delivered to the farmer.

The phosphorus in the rock occurs as tricalcium phosphate, $Ca_3(PO_4)_2$, combined with some fluorine and chlorine. The phosphorus in this form is regarded as "unavailable" to plants. The following conventional formulas represent the changes that take place in the phosphorus during the process of making superphosphate. Undoubtedly, many complicated side reactions take place simultaneously.

$Ca_3(PO_4)_2$ Tricalcium phosphate	+	H_2SO_4 Sulphuric acid	=	$Ca_2H_2(PO_4)_2$ Dicalcium phosphate	+	$CaSO_4$ Calcium sulphate
$Ca_2H_2(PO_4)_2$ Dicalcium phosphate	+	H_2SO_4 Sulphuric acid	=	$CaH_4(PO_4)_2$ Monocalcium phosphate	+	$CaSO_4$ Calcium sulphate

The dicalcium phosphate is soluble in a standard-strength solution of citrate or citric acid. The monocalcium phosphate is soluble in water. The combined percentages of dicalcium and monocalcium phosphates constitute that which is rated as "available" phosphoric acid in superphosphate. Approximately one-half of superphosphate thus made consists of calcium sulphate, the principal ingredient of gypsum. This calcium sulphate supplies calcium and sulphur that may be of value to plants under many soil conditions.

Superphosphate that carried 16 or 20 per cent of phosphoric acid was considered standard until recently. At the present time, 32, 40, and 45 per cent superphosphates are on the market, sometimes under the designations of "double" and "treble" superphosphates. In order to produce these higher-analysis superphosphates, phosphoric acid is used instead of sulphuric acid for treating the phosphate rock. When this is done, no

[1] As an average of the 12 years, 1927 to 1938, 3,800,000 tons of superphosphate were made in the United States. In 1937, the tonnage was 4,800,000 and, in 1938, 4,005,000, according to the *Fertilizer Rev.*, Vol. 14, No. 1, p. 15, 1939.

calcium sulphate is produced and the final product is much higher in phosphorus than when sulphuric acid is used. Economy in transportation and handling charges accompanies the use of these higher-analysis superphosphates. A ton of 32 per cent superphosphate, for example, carries as much actual phosphorus as 2 tons of the 16 per cent grade. Likewise, the 40 and 45 per cent grades are distinctly more concentrated than the 16 and 20 per cent grades. Accordingly, bags, transportation, and labor charges for handling, storing, and spreading per pound of phosphoric acid are less than with the lower-analysis goods. Under conditions, however, where calcium or sulphur, or both, are beneficial to crops, the higher analyses may not give such good results as 20 per cent superphosphate.

Ammoniated Superphosphate.—In recent years, ammonia mixed with urea, or sodium, or ammonium nitrate has been added to superphosphate. The reaction between ammonia and monocalcium phosphate may be represented as follows:

$$CaH_4(PO_4)_2 + NH_4OH = NH_4H_2PO_4 + CaHPO_4 + H_2O$$

It should be noted that the ammonia displaces calcium in part of the monocalcium phosphate and results in the formation of monoammonium phosphate and at the same time of dicalcium phosphate. A reversion from the monocalcium to the dicalcium phosphate has been brought about. The addition of ammonia to the extent of 2.3 per cent in 20 per cent superphosphate has been found to be feasible. Correspondingly more ammonia may be added to 32 and 40 per cent superphosphates. Additional ammoniation causes the formation of tricalcium phosphate, but this is more readily available than that in the original rock phosphate. This reversion and loss in availability of the phosphoric acid are undesirable; consequently, the addition of ammonia is restricted to the equivalent of about 2 per cent of nitrogen. Ammoniated superphosphate is a highly desirable product, particularly because ammoniation improves the physical properties of the superphosphate. Moreover, ammoniated superphosphate is particularly useful in mixed fertilizers.

It is well known that the phosphoric acid in superphosphate does not long remain in the "available" condition after it is mixed with the soil. In acid soils, the mono- and dicalcium phosphates unite readily and quickly with soluble compounds of iron and

aluminum in the soil. Iron and aluminum phosphates are insoluble; and the phosphorus in them, therefore, is relatively unavailable to plants. In soils that contain sufficient calcium, the available phosphates revert to the original tricalcium form which is regarded as insoluble and unavailable to plants. Since it is a newly formed chemical compound, however, tricalcium phosphate does serve plants as a source of phosphorus. The absence of fluorine and chlorine are probably factors in the availability of this tricalcium phosphate as compared with the ordinary rock phosphate. Over a narrow range of slight acidity, these available phosphates remain in an available condition or at least do not become "fixed" in the soil so rapidly as they do under distinctly acid or under alkaline conditions.

The granulation of superphosphate, cyanamide, and nitrate of soda and of mixed fertilizers is a recent development. A considerable portion of the fertilizer is changed from a pulverized to a granular condition. In this condition, the fertilizer drills freely and in the case of superphosphate retains its availability in the soil better than in the pulverized state. When granulated materials are mixed without grinding, the resulting mixture is probably less homogeneous than if pulverized materials are mixed. On the whole, however, the use of granulated materials and the granulating of mixed fertilizers may be regarded as a progressive measure.

Metaphosphate.—Metaphosphate is a high-concentration phosphate that contains about 63 per cent of phosphoric acid. It is being made on a small scale by the Tennessee Valley Authority. In its manufacture, phosphorus in gaseous form is brought into contact with rock phosphate at temperatures of approximately 1200°C. When cooled, the resulting product has a glassy appearance. It is ground to a suitable fineness for use on the soil. Trials that have been made indicate that metaphosphate supplies phosphorus to plants in available form and that they produce good increases in yield from its use.

By-product Phosphate.—Basic slag is the leading by-product that has real value as fertilizer for its phosphorus content.

Basic Slag.—Basic slag contains 8 to 25 per cent of phosphoric acid and varying quantities of calcium. The slag produced in this country carries 8 to 10 per cent of phosphoric acid. Since this is a rather low percentage, domestic slag is not widely

used, particularly at considerable distances from the point of production.

The phosphorus in basic slag is available and apparently remains available in the soil. In this respect, slag has a distinct advantage over superphosphate, particularly for meadows and pastures on acid soils.

Comparison of the effectiveness of basic slag with that of superphosphate is somewhat difficult. Slag carries appreciable quantities of manganese, calcium, magnesium, and iron. Superphosphate, on the other hand, contains much calcium and sulphur. The calcium in slag can serve as a nutrient and can also correct acidity, whereas the calcium in superphosphate is in combination which usually does not materially affect the acidity of the soil. On unlimed acid soils, basic slag, on the basis of equal quantities of phosphorus, may be expected to give results superior to those from superphosphate. Such was found to be the case with clover in Ohio. In contrast, the calcium in basic slag might tend to encourage scab on potatoes on soils that contain considerable calcium.

CARRIERS OF POTASSIUM

The bulk of the potassium used in the fertilization of crops is applied in the form of salts usually more or less refined. The potash[1] salts come from underground deposits and from saline lakes. Searles Lake in California is the leading surface deposit of this type that is being worked in the United States. Formerly, the potash salts were imported mainly from Germany and France. Seaweed, growing on the Pacific Coast, upon being burned, yields ash that contains up to 30 per cent of potash and other valuable products. Certain wastes and by-products, also, are used.

During recent years, however, immense underground deposits of high-grade potash salts have been discovered near Carlsbad, N. M. (Figs. 148, 149, and 150). These are now being worked under lease from the federal government by three large producers. These deposits together with the deposit of Searles Lake and the industrial by-products are capable of supplying the American agricultural and commercial demand for potash. As late as

[1] Potash, K_2O, is the oxide of potassium, K, 0.83, or 83 per cent, of potash being actual potassium.

Fig. 148.—Potash mine near Carlsbad, N. M. After the potash-bearing salts have been blasted loose the material is loaded into the cars (at left) with an electric shovel. (*Courtesy of American Potash Institute, Inc., J. W. Turrentine, Pres.*)

Fig. 149.—Transporting potash salts underground. The potash salts are hauled by the electric engine through the galleries to the dumping station from which they are hoisted to the surface. (*Courtesy of American Potash Institute, Inc.*)

1939, however, a considerable share of our agricultural needs was still being supplied from abroad.

Fig. 150.—Aboveground potash works. This illustrates something of the magnitude of one of the three potash producers in New Mexico. (*Courtesy of American Potash Institute, Inc.*)

Underground and Lake Deposits.—The underground and lake deposits supply muriate of potash (KCl), kainit, and manure salts which are similar to those that have long been imported from Europe.

Muriate of Potash.—Muriate of potash is refined from the crude salts. Formerly this product carried 50 per cent of potash; the product coming from the New Mexico producers carries about 62 per cent. This salt is water soluble, and the potash, therefore, is readily available to plants. An equally high-grade muriate is produced at Searles Lake in California by the American Potash and Chemical Corporation, a corporation organized during the period of potash shortage in the United States soon after 1915 and still continuing production. The Potash Company of America, the United States Potash Company, and the Union Potash and Chemical Company are all operating near Carlsbad, N.M. The present plant capacity in this country is ample for immediate domestic needs.

Sulphate of Potash.—Sulphate of potash, or potassium sulphate, contains 48 to 50 per cent of potash and must not exceed 2.5 per cent of chlorine. Sulphate of potash is separated from the muriate in the crude salts and brines. The sulphate is regarded as being superior to the muriate for tobacco and, in a measure, for potatoes. Some muriate can be used for tobacco, but too much chlorine is detrimental to the crop in various ways.

Sulphate of Potash-magnesia.—Sulphate of potash-magnesia is a double salt that carries 25 per cent of potash and 25 per cent of sulphate of magnesia and not more than 2.5 per cent of chlorine. It is used in the production of tobacco.

Manure Salts.—Manure salts have 20 to 30 per cent of potash. Crude salts carrying 20 per cent of potash as mined formerly were sold as manure salts. They consist of muriate with a little sulphate of potash, common salt, and impurities. Some of the salts from New Mexico have 26 per cent of potash as mined. Higher percentages of potash are obtained by adding refined potash salts.

Kainit.—Kainit contains 14 to 20 per cent of potash. This potash carrier is the crude salt as mined and ground ready for application to the soil. It consists mainly of muriate and impurities. Owing to high carrying charges and the higher concentration of present-day mixed fertilizers, kainit is probably less used now than formerly.

By-product Potash.—Several by-products are valuable sources of potash. Among them are ashes, tobacco stems, flue dusts, and alcohol residues.

Ashes.—Wood and other ashes vary widely in potash content. Fresh, clean hardwood ashes contain 4 to 7 per cent of potash, 1.5 to 2.0 per cent of phosphoric acid, and 20 to 35 per cent of lime, CaO. In the early days, fine timber was cut and burned for the ashes. These ashes were leached and the liquid lye boiled down in pots. The resulting product was a fairly concentrated mixture of potassium carbonate and impurities. Exporting this potash to Europe was a source of cash for the Colonists. The name *potash* originated from the words *pot ashes* and has persisted, perhaps, because of its resemblance to the word potassium. Though of importance formerly, wood ashes as a source of potash are unimportant now except locally. Carbonate of potash from the ash of various organic wastes contains 15 to 50 per cent of potash.

Tobacco Stems.—Tobacco stems carry 4 to 9 per cent of potash and some nitrogen (see page 321).

Flue Dusts.—Potash in large quantities is lost in the manufacture of cement as flue dust and fumes. A large share of the potash in the fumes is in gaseous form and can be recovered rather easily. The dust also might be saved as a by-product

with comparative ease. It carries about 3 to 10 per cent of potash.

Alcohol Residues.—The lowest grades of molasses contain essentially all the potash that was in the juice of the cane or the sugar beets. Upon conversion of the sugar in the molasses into alcohol, the potash remains. This waste is burned and goes to the fertilizer industry as *vegetable potash.* It contains about 33 per cent of potash.

MISCELLANEOUS FERTILIZER MATERIALS

In this classification are placed many materials that carry more than one of the principal fertilizer elements, nitrogen, phosphorus, and potassium.

Ammophos.—Ammophos is produced by combining ammonia and phosphoric acid. It comes in two grades. One carries 11 per cent of nitrogen and 48 per cent of phosphoric acid. The other is more completely ammoniated and contains 16 per cent of nitrogen and 20 per cent of phosphoric acid.

Nitrophoska.—Nitrophoska is a complete fertilizer in that it carries all three elements. The nitrogen present is produced synthetically. This product which has been imported from Germany is a high-grade concentrated fertilizer.

Phosphate of Potash.—Phosphate of potash contains varying percentages of its two elements, 32 to 50 per cent of phosphoric acid and 50 to 30 per cent of potash. The higher percentage of potash goes with the lower percentage of phosphoric acid.

CARRIERS OF SULPHUR AND TRACE ELEMENTS

In certain sections of the country, definite need exists for the application of sulphur and in others for trace elements.

Sulphur.—Sulphur is, of course, definitely known to be an essential plant-nutrient element. In many sections, the sulphur in the soil and that coming to the earth in rain water are ample for normal plant growth. The sulphur supplied in rainfall varies greatly in different areas. Wilson[1] found over a period of 2 years that 26.19 pounds of sulphur came to the soil in rain water at Ithaca, N.Y. He reported 45.10 pounds an acre at Urbana, Ill.; 6.97 at Rothamsted, 38.32 at Garforth, and 64.58 pounds at

[1] WILSON, B. D., Sulphur Supplied to the Soil in Rain Water, *Jour. Amer. Soc. Agron.*, Vol. 13, pp. 226–229, 1921.

Leeds, England; and 5.98 in New Zealand, as coming to the soil from the air.

Sulphur is supplied in manure, sulphate of ammonia, sulphate of potash, and superphosphate; and it may be obtained for use on the soil as land plaster, or gypsum, and as sulphur. Because of its tendency to produce intense acidity, some care may well be employed in the use of elemental sulphur.

Trace Elements.—The essential trace, or minor, elements supplied in fertilizers are copper, manganese, zinc, and boron. They are required in traces only; hence their name. They are added to fertilizers where it it believed that they are needed for a special crop or in a particular area. Copper, manganese, and zinc are used as the sulphate and boron as the sodium salt.

For convenience, the percentages of plant nutrients in the more important fertilizer materials are brought together in Table 57 in alphabetical order in three groups, ammoniates, phosphates, and carriers of potash.

EFFECTS OF NITROGEN, PHOSPHORUS, AND POTASSIUM ON PLANTS

Each of the fertilizer elements has its own particular function in plant nutrition and its own more or less independent effect on the growth and functioning of plants.

Nitrogen.—Nitrogen acts quickly within the plant. A crop showing by its yellowish-green color evidence of lack of nitrogen quickly changes to a dark healthy green following the application of moderate quantities of available nitrogen. Nitrogen stimulates the growth of both leaf and stem, the so-called "vegetative" parts of the plant. Lack of sufficient nitrogen is shown, also, by short stalks of some crops. An abundance, particularly an excessive supply, of nitrogen produces a watery, succulent growth, a type of growth desirable in leafy vegetables such as celery, lettuce, and spinach but very undesirable in grains and some fruits. Grains tend to have long, weak straw and to lodge badly very early as a result of large supplies of nitrogen, especially if the supply of moisture also is excessive.

Because of this quick action of nitrogen, even lightly fertilized crops may show response to fertilization in the form of increased vegetative growth. Nitrogen from the soil does not affect the crop so early as does available nitrogen that is applied at seeding

time. Often the grain crop that is fertilized with phosphorus alone catches up later in the season and outyields that which was stimulated by the small amount of nitrogen in the complete fertilizer applied to the grain. This early effect of nitrogen may mislead the farmer who makes no comparison of actual yields but who depends entirely on the appearance of the crop.

Excessive use of nitrogen may have several detrimental effects. It may delay ripening of fruits, vegetables, and other plants that produce ripe seed, and such delay sometimes results in damage from frost. Excess nitrogen produces poor quality in peaches. The wood of this fruit is sensitive to winter injury, and this is particularly true if its maturity is delayed by an excessive supply of nitrogen. The lodging of grains results from the weakness and excessive length of the internodes. And because of lodging the yield of grain is usually reduced and the quality of it lowered. Such grain often is "chaffy." Finally, too much nitrogen, particularly if accompanied by abundant moisture, appears to lessen the resistance of plants to disease. For all these reasons the use of nitrogen to excess is to be guarded against.

Phosphorus.—Phosphorus tends to counteract and balance the effects of an excess of nitrogen, particularly by increasing resistance to disease. Moreover, many functions of plants cannot be carried on in the absence of sufficient phosphorus. Phosphorus encourages blooming and the setting of seeds and hastens maturity. In late seasons or in areas that have a short growing season, this element is likely to hasten the ripening of a crop so that it may escape frost. Applying an abundance of phosphorus under these conditions often pays handsome profits.

Phosphorus encourages the development of the fibrous roots of crops, especially of such fall-seeded ones as wheat. This effect enables the crop to withstand winterkilling and to make rapid early-spring growth. It has been observed frequently that wheat treated with phosphorus made an especially early start and strong, vigorous growth in the spring. In both fall and spring, the phosphorus-treated wheat made a better showing than that treated with nitrogen.

Phosphorus by balancing the unfavorable conditions created by an excess of nitrogen stiffens the straw of cereals and thus reduces the tendency toward lodging. Seeds are relatively rich in phosphorus, and an addition of it, therefore, increases yields.

This is particularly true of grains, the kernels of which are plumped by phosphorus. Phosphorus improves the tone and vigor of plants and finally the quality of the crop. Especially notable is this effect in ripe fruit such as tomatoes, peppers, and others.

No undesirable effects even from heavy applications of phosphorus have been noted, although they are conceivable on light, dry soils as a result of excessive applications.

A shortage of phosphorus is indicated by the development of a purplish or bronze color of foliage. This has been observed in pastures by the author and on various plants by other workers. The untreated soil had purplish-green blades, whereas the grass that had received 125 pounds of phosphoric acid (800 pounds of 16 per cent superphosphate) to the acre was of a normal green color. The first rain apparently spread the soluble phosphorus from higher on the slope over the untreated strips so that the entire phosphorus-treated area soon took on a normal green color. The lack of phosphorus on narrow strips resulted from the slipping of the phosphate spreader on the steep slope in this pasture. Many soils unfortunately are deficient in phosphorus.

Potassium.—The proper quantity of available potassium along with a goodly supply of the other elements improves tone and vigor and produces healthy growth. By balancing the effects of nitrogen, potassium, like phosphorus, improves the natural resistance of plants to disease. In contrast, potassium, in common with nitrogen, delays the ripening of many crops. In this respect, the effect of potassium counteracts that of phosphorus. Potassium is required for the formation of chlorophyll. With energy from the sun, chlorophyll produces starch for which potassium is essential.

Extremely heavy applications may be detrimental to certain crops that appear to be sensitive to excessive supplies of potassium. Normal, properly placed applications, however, usually produce only beneficial effects.

EFFECTS OF FERTILIZER MATERIALS ON SOILS

Some fertilizer materials leave in the soil an acid residue of which that from sulphate of ammonia is a good example. Others tend to make the soil alkaline. Nitrate of soda and calcium cyanamide have this effect. Nitrate of soda in heavy applica-

TABLE 57.—PERCENTAGES OF PLANT NUTRIENTS IN FERTILIZER MATERIALS AND RESIDUAL EFFECTS UPON THE SOIL

Material	Nitrogen	Phosphoric acid	Potash	Residual effect upon the soil: Reaction	Residual effect upon the soil: Limestone required for neutralization of residual acidity from 1 ton of fertilizer material,* pounds	Residual effect upon the soil: Limestone equivalent of residual alkalinity from 1 ton of fertilizer material,* pounds
Ammoniates						
Ammonium chloride	24					
Ammonium nitrate	35	....	....	Acid	1,250	
Ammophos (1)	11	48	....	Acid	1,097	
Ammophos (2)	16	20	....	Acid		
Animal tankage	5–10	3–13†	....	Neutral		
Blood, dried	8–14	....	....	Acid	457	
Calcium nitrate	15	....	....	Slightly alkaline	.....	400
Cal-nitro	20.5	....	....	Neutral		
Calurea	34	....	....	Acid	1,200	
Castor meal	4.5–6.5	1.0–1.5	1–1.5	Slightly acid	120	
Cocoa cake	3.5–4.5					
Cocoa shells	2.5	....	....	Neutral		
Cotton-seed meal	6–9	2–3	1.5–2.0	Slightly acid	200	
Cyanamide (commercial)	22	....	....	Alkaline	.....	1,260
Fish (acid)	4.0–6.5	3–6	....	Slightly acid	100	
Fish tankage	6.5–10	4–8	....	Slightly acid	100	
Garbage tankage	2.5–3.3	....	....	Alkaline	.....	134
Guano	10.5	10				
Leunaphos	20	20				
Leuna salpeter	26	20	....	Acid		
Linseed meal	5	1.5				
Milorganite	5–6	1–5				
Nitrate of soda	16	....	....	Alkaline	.....	583
Nitrate of potash	12–14	....	44–46	Alkaline		
Nitrate of soda-potash	15	....	15	Alkaline		
Nitrogenous tankage	6–10	....	....	Acid	320	
Nitrophoska	Variable	Variable	Variable	Acid		
Peat or muck	1–3					
Sulphate of ammonia	20.5	....	....	Acid	2,249	
Uramon	42	....	....	Acid	1,500	
Urea	46	....	....	Acid	1,660	
Phosphates						
Basic slag (imported)	....	10–25	....	Alkaline	.....	1,015‡
Bone black	1–2	32–35†	....	Alkaline	.....	1,413
Bone meal (raw)	2–4	20–25†	....	Alkaline		
Bone meal (steamed)	1–2	23–30†	....	Alkaline	.....	500
Metaphosphate	......	63				
Rock phosphate	....	28–32†	....	Alkaline	.....	200
Superphosphate	....	16–45	....	Neutral		
Superphosphate ammon.	2	16	2	Acid	115	
Carriers of Potash						
Ashes (wood)	....	1.5–2	4–7	Alkaline	.....	500–1,000
Carbonate of potash	....	....	15–50	Alkaline		
Carbonate of potash-magnesia	....	....	24–27	Alkaline		
Kainit	....	....	14–20	Neutral		
Manure salts	....	....	20–30	Neutral		
Muriate of potash	....	....	50–62	Neutral		
Nitrate of potash	12–14	....	44–46			
Phosphate of potash	....	32–53	50–30			
Sulphate of potash	....	....	48–52	Acid		
Sulphate of potash-magnesia	....	....	25–27			
Tobacco stems	1.2–3.3	....	4–9	Neutral		

* PIERRE, W. H., Determination of Acidity and Basicity of Fertilizers, *Jour. Ind. Eng. Chem.*, Vol. 5, p. 29, 1933.
† Not wholly available. ‡ Cornell University, Agronomy Department, unpublished data.

tions over a period of years, it has been observed in places, appears to puddle the soil. This puddling is the effect of the soda residue. Presumably, in time the acidifying fertilizer materials will have a bad effect on the structure of the soil because of the removal of calcium. Except in strongly acid soils, this effect of sulphate of ammonia may be delayed for some years.[1]

Deteminations have been made of the limestone equivalent of the alkaline effect per ton of fertilizers which supply basic materials and of the limestone required to neutralize the acid effect of those which tend to produce an acid condition of the soil. The nitrogenous fertilizer materials have the more marked effects on the reaction of the soil. The *limestone equivalents* from the standpoint of acidity and alkalinity effects of many fertilizer materials are given in Table 57.

Questions

1. What is meant by fertilizers?

2. Distinguish between organic and inorganic and synthetic carriers of nitrogen.

3. Name the important carriers in each group, and state their nitrogen content.

4. Name the important carriers of phosphorus, and state their sources, relative availability, and percentages of phosphoric acid.

5. Discuss the sources of the various carriers of potash, and state their potash content.

6. What is the possible importance of by-product potash?

7. Discuss important miscellaneous fertilizer materials.

8. State the sources and relative importance of sulphur and the trace elements in fertilizer.

9. What are the most notable effects of nitrogen, phosphorus, and potash on crops?

10. What are the residual effects of fertilizer materials on soils?

[1] Additional information may be found in Fertilizer Problems and Analysis of Soils in California by D. R. Hoagland, *California Agr. Exp. Sta., Circ.* 317, 1939.

CHAPTER XVI

COMMERCIAL FERTILIZERS AND THEIR USE

The sources and composition of fertilizer materials, together with the effects of nitrogen, phosphorus, and potassium on crop plants and of the residues from these materials on soils, have been discussed in the preceding chapter. Additional information bearing on mixed fertilizers and their use is presented in the following pages.

Fig. 151.—Effect of phosphorus and potash on growth of clover. The soil is a gravelly loam somewhat sandy in character. This red clover was thoroughly inoculated and, therefore, obtained nitrogen from the air since none was applied. Being coarse textured this soil would be expected to be deficient in both phosphorus and potash. The crop was markedly improved by applications of both phosphorus and potash. (*Photograph by the author, Cornell Univ. Agr. Exp. Sta.*)

Fertilizers Used to Supplement Nutrients from the Soil.—Under normal conditions, crops obtain nutrients from the soil but often in quantities that are insufficient for satisfactory yields. There are a number of reasons to explain this. (1) Many soils were but meagerly supplied with phosphorus originally. Although medium- and heavy-textured soils usually had an abundance of potassium, fortunately, neither it nor phos-

phorus was readily available to crops—fortunately, because if they had been readily available, these essential nutrients would have been lost ages ago. Coarse-textured soils are often low in both phosphorus and potassium (Figs. 151, 152, and 153). (2)

FIG. 152.—Effect of fertilizing corn in Ohio. Extreme left, manure and superphosphate and complete fertilizer in the hill; yield 89 bushels to the acre. Middle, no fertilization, 39 bushels to the acre. Extreme right, fertilizer in the hill only, yield 62 bushels to the acre. (*Courtesy of E. E. Barnes, Ohio Agr. Exp. Sta.*)

FIG. 153.—Effect of omitting nitrogen from the fertilization of tobacco. Complete fertilizer applied at left, nitrogen omitted at right. (*Reproduced from U.S. Dept. Agr., Tech. Bull.* 414.)

Though an area of prairie soils in the Midwest was relatively well supplied with organic matter and nitrogen, the forested lands were comparatively deficient in both organic matter and nitrogen in active form. (3) During the years of cropping, washing, and leaching, much of the more readily available nutrients in the virgin soil has been lost. For all these reasons the addition of nutrients to the soil, which constitutes the use of fertilizer, is

necessary in order to produce satisfactory yields of important crops on many soils.

Single Fertilizer Materials Often Sufficient.—A single fertilizer material such as superphosphate that supplies one fertilizer element, namely, phosphoric acid, often is all that can be used to the farmer's financial advantage. This condition holds for feed crops in large areas of the Northeastern states. In the Midwest, finely ground rock phosphate has for some years served in a similar manner in that it has been used to supply phosphorus for grain and forage crops. Ashes were used alone a good many years ago as a source of potash; but, of course, they supplied lime in addition. Guano and nitrate of soda have been used alone, and the latter has served as a side dressing for high-return crops. Fertilization by means of carriers of phosphorus alone, however, has been most widely practiced in this country. In Europe, the carriers of the fertilizer elements are often applied separately, and good results are obtained.

For such crops as vegetables, cotton, potatoes, tobacco, and others, however, phosphorus alone is insufficient. In fact, all three fertilizer elements are needed. The European method may involve more labor in applying fertilizer than the American one. Such added costs, however, are at least partly offset in this country by the cost of mixing fertilizer in advance of application.

According to Willett,[1] American farmers used 8,196,000 tons of fertilizer in 1937, 7,489,000 tons in 1938, and 7,589,000 tons in 1939 (exclusive of the concentrated superphosphate distributed by the Agricultural Adjustment Administration). Large use of fertilizer in recent years has led to the development of the immense American fertilizer industry.

Fertilizer Terms.—Before entering upon a discussion of mixed fertilizers, an explanation of certain fertilizer terms is essential to an understanding of their use. Among them are: *unit; formula; analysis; mixed, complete,* and *incomplete* fertilizers; *drier,* or *conditioner; ratio;* and *guarantee.*

Unit.—The term unit as used in the fertilizer industry means 1 per cent in a ton, or 20 pounds. A fertilizer that contains 5 per cent of nitrogen, 10 per cent of phosphoric acid, and 5 per cent of

[1] WILLETT, HERBERT L., Fertilizer Consumption in the United States, *Fertilizer Rev.,* Vol. 15, No. 2, p. 12, 1940.

potash is said to carry 5 units each of nitrogen and potash and 10 units of phosphoric acid, or a total of 20 units. Rock phosphate, potash salts, and tankage have been marketed to some extent on the basis of a contract price per unit of actual phosphorus or phosphoric acid in the rock phosphate, potash in the potash salts, and nitrogen in the tankage. The fertilizer-unit idea is very useful in comparing the concentrations of various mixed fertilizers.

Formula.—The fertilizer formula is the statement of the quantity of each ingredient that is used in a given mixed fertilizer. The quantity of each ammoniate, including the conditioner, the quantity of superphosphate or other carrier of phosphorus, and the quantity of the different carriers of potash are all given in the formula. The amount of nitrate nitrogen used is sometimes stated, in addition.

In the *open* formula, the manufacturer of a fertilizer states plainly on the package the quantity of each ingredient that was used in making 1 ton of a particular fertilizer. If information is not given as to the amount of each ingredient used, the formula is said to be a *closed*, or *secret*, one.

Analysis.—The analysis of a fertilizer is the percentage of total nitrogen, of available phosphoric acid or phosphorus, and of water-soluble potash. A fertilizer whose analysis is said to be 5-10-5 carries 5 per cent of total nitrogen, 10 per cent of available phosphoric acid, and 5 per cent of water-soluble potash. Some years ago, fertilizers that had less than 14 per cent, or 14 units, of plant nutrients were regarded as of *low* analysis, and those with more than 14 units were called *high*-analysis fertilizers. Today, with the higher-analysis fertilizer materials available, anything containing less than 20 units is to be regarded as of distinctly low analysis; in fact, 24 units is not very high. Fertilizers that contain more than 30 units can now be made so readily that even 20 or 24 per cent fertilizers are not of really high analysis. Fertilizers are being made that carry 40 and even 60 units of plant nutrients.

Mixed Fertilizers.—Mixed fertilizers are those which consist of a number of ingredients mixed in order to obtain the desired analysis. A few or many ingredients, depending on conditions, may go into mixed fertilizers. A mixed fertilizer that contains all three of the so-called fertilizer "elements," nitrogen, phosphoric acid, and potash, is called a *complete* fertilizer. In con-

trast, one that carries only two of the three fertilizer elements is sometimes referred to as an *incomplete* fertilizer.

Drier, or Conditioner.—Some fertilizer materials take up water readily from a moist atmosphere. Such materials are said to be *deliquescent,* or hygroscopic, in nature. When certain ingredients are mixed, products are formed that take up water readily and that may cause lumping or caking of the resulting mixture. In order to keep mixed fertilizers in such condition that they will flow readily through fertilizer distributors, materials that take up moisture are introduced into the mixture. Such materials are known as *driers,* or *conditioners.* By absorbing the moisture taken up by deliquescent materials, the driers, or conditioners, maintain good drilling qualities. The organic materials, such as the tankages and seed meals, calcium cyanamide, and peat, serve well as driers. Because of their drying properties, the animal and vegetable organics command a premium on the market above the true value of the nitrogen in them.

Ratio.—In recent years, the number of mixed fertilizers on the market has grown rapidly. Many of the low-analysis fertilizers that were on the market 30 years ago are still being sold along with the higher-analysis ones. The 4-8-4 has long been a favorite with vegetable growers. Then came a demand for a similar mixture that was more concentrated, and the 5-10-5 satisfied the demand for a time. Soon after that, progressive manufacturers placed the 8-16-8 on the market. This was followed by the 10-20-10 and even by the 12-24-12. By applying the greatest common divisor, it is found that these mixtures are indeed very similar 4-8-4 ÷ 4 = 1-2-1 and 5-10-5 ÷ 5 = 1-2-1, and so on, through the entire list. All of them possess the identical 1-2-1 ratio between the plant-nutrient elements. Each of them contains twice as many units of phosphoric acid as of nitrogen or potash.

If the 4-8-4 is a suitable fertilizer for a given vegetable crop, any other fertilizer of the same ratio should also be desirable. A ton of 4-8-4 carries the identical quantity of nutrients as 1,600 pounds of 5-10-5, or 1,000 pounds of 8-16-8, or 800 pounds of 10-20-10, or 667 pounds of 12-24-12 fertilizer. Instead of making so long a statement, a recommendation can read "1,600 pounds an acre of a 5-10-5 fertilizer or its equivalent in any fertilizer having the 1-2-1 ratio," or, more simply still, one could advise

using "320 pounds of nutrients to the acre in a fertilizer with the 1-2-1 ratio." In fertilizer discussions, therefore, the term ratio really is highly useful.

Guarantee.—A fertilizer guarantee is the manufacturer's warranty that the fertilizer bag contains the actual quantities of plant nutrients called for in the printed statement on the bags or on tags attached to the bags. In the guarantee nitrogen is expressed as *total* nitrogen, phosphorus as *available* phosphoric acid, and potassium as *water-soluble* potash.

Public Control of Composition of Fertilizers.—During the early days, fertilizers were sold as "corn," "wheat," or "potato" fertilizers, or a fertilizer might be marketed under a name such as "potato special." Chemical analyses of the ingredients used in fertilizers were not so reliable then as they are today. Moreover, facilities for complete control by the manufacturer of the quality and quantities of the various materials used in mixtures were not thoroughly developed. Possibly, at times, also, the farmer had reason to believe that certain mixed goods did not contain all that was called for in the guarantee. At any rate, a demand grew up for control by the states. It was recognized from the start that such control protected both the user and the manufacturer of fertilizers.

Fertilizer "control" laws are now on the statute books of nearly all the states. A tax is imposed on the manufacturers of fertilizers in order to support the control service. This is accomplished in various ways, by means of a tonnage tax in some states and by an annual fee in others. Many states in the heavy fertilizer-using area of the Southeast impose a tax on each ton of fertilizer sold by each manufacturer. As an example of the annual fee, New York taxes each manufacturer a fixed annual amount for each brand or analysis of mixed fertilizer and for each fertilizer material licensed in the state for sale by him during the year. Under the fee system, the small producer pays as much as does the large manufacturer. From this standpoint, the tonnage tax is more equitable, and in addition the state officials know at all times the quantity of fertilizer on which the tax has been paid.

Fertilizer laws vary somewhat. But the usual requirements are that the maker or selling agent give: (1) his address; (2) the brand, name, or trade-mark; (3) the guaranteed analysis; (4) the net quantity of fertilizer in the bag or package.

As a check on the composition of fertilizers with respect to guarantee, a system of state inspection and analyses is maintained. The inspectors collect samples of fertilizers and materials that are actually on the market in their respective states. These are sent to the state laboratory for analysis. Upon completion, the analyses are published as the annual "fertilizer analysis," or control bulletin for the state. Such publicity is particularly effective. No manufacturer wishes to see his goods publicly shown to be *below* guarantee. In fact, great effort is made by manufacturers to be certain that the analysis found by the state chemist shall exceed their guarantees by at least a small margin. In view of the possibility of lack of uniformity in mixing or of deficiency in the original ingredients, the number of analyses that fall below the guarantees is surprisingly small.

Under the laws, the enforcing agent, often the head of the state department of agriculture, may and occasionally does impose fines on manufacturers because of deficiencies in analysis. As already stated, however, the imposition of fines is relatively rare because deficiencies are not numerous.

FACTORY MIXING OF FERTILIZERS

Fertilizers today are manufactured by a giant chemical industry. Some manufacturers produce most of their materials, including the mining of the phosphate rock and the making of sulphuric acid and superphosphate from these two materials. Some make synthetically a portion of the ammoniates used, and others recover their own packing-house by-products. Those who make their superphosphate are sometimes called *wet mixers*. These manufacturers are in a position to use wool, hair, feathers, felt, and other wastes along with rock phosphate in the manufacture of *wet-base* goods. The action of the sulphuric acid on the organic wastes renders the nitrogen in them available at the same time that the phosphorus is being changed to available forms. The addition of ammonia to superphosphate in liquid or gaseous form is a recent development that has proved to be distinctly economical, in part because of an increase in concentration of the finished goods and because ammoniation improves the drilling quality of the mixture.

After this material is cured and ground, the needed ammoniates, conditioner, and potash-bearing materials are added, mixed

and cured as may be necessary. The mass is then remilled, screened, and bagged ready for delivery to the consumer.

At the other extreme is the small fertilizer mixer who buys all his materials and mixes them in the dry state. This is called *dry mixing*. Ammoniates, superphosphate, conditioner, and potash salts are mixed and, if necessary, cured. Afterward, the mixture is reduced in fineness so as to ensure suitable drillability.

HOME MIXING OF FERTILIZERS

Under certain conditions, farmers mix fertilizers on the farm. Some farmers desire special fertilizer mixtures that they regard as particularly suited to their soils or that they think are particularly desirable for their crops. If the special mixtures are not readily available on the fertilizer market, they may be mixed at home. And, moreover, a distinct saving in cost can often be made by home mixing fertilizers, provided that the ingredients can be purchased at favorable prices and the amount of fertilizer needed justifies the trouble.

Procedure in Home Mixing of Fertilizers.—Several preliminary steps are essential in this work. First, the prices of the separate fertilizer materials should be obtained and also the price of the desired analysis of ready-mixed fertilizer. A comparison will indicate the possible saving, and a decision may then be reached as to whether home mixing will pay. If it seems that it will, the second step is to decide upon the formula that is to be mixed and the quantity of each ingredient needed. Large orders often command lower prices whether for ingredients or for ready-mixed fertilizers.

For home mixing, relatively concentrated materials are usually more economical than the less concentrated ones, for higher concentrations mean less cost for delivery and less labor in handling and mixing per unit of nutrients. Using a small number of materials, particularly if the entire order is small, leads to economy in purchasing. Most fertilizer materials may be mixed with many of the others without encountering any difficulty. Materials that carry much free calcium in any form ought not to be mixed in large proportions with superphosphate because calcium may reduce the availability of the phosphorus. Because of their deliquescence, urea and calcium nitrate are unsuited for use in home-mixed fertilizers.

As an example, assume that a 10-20-10 fertilizer is desired for late potatoes, nitrate not being regarded as essential. The analysis calls for 10 pounds each of nitrogen and potash in each 100 pounds of fertilizer. For a ton (10 × 20 hundreds in a ton), 200 pounds each of nitrogen and of potash and 400 pounds of phosphoric acid are required. These quantities of nutrients may be obtained from the following materials:

200 lb. tankage, 5 per cent N, 10 lb. N = drier or conditioner
453 lb. uramon, 42 per cent N, 190 lb. = 200 lb. N required
1,000 lb. superphosphate, 40 per cent P_2O_5 = 400 lb. P_2O_5 required
334 lb. muriate of potash, 60 per cent K_2O = 200 lb. K_2O required
1,987 lb. total

Four ingredients supply the materials for this high-analysis fertilizer which carries a total of 40 units of plant nutrients. A tankage that contains only 5 per cent of nitrogen is not a high-analysis material, but it is a suitable conditioner and probably the most economical one. The other 13 pounds may be peat, sand, dolomite, or other material, although it is not essential that a further addition be made, 1,987 pounds being near enough to a ton for all practical purposes. Formulas for other analyses can be readily worked out.

If other farmers are interested, the third step is the pooling of orders. Each participant in the pool works out his formula and, on the basis of the quantity of fertilizer needed, determines the quantity of each material to be purchased. The quantities are then covered in a single order, delivery being arranged for in the most economical way by freight or truck. The materials are best stored in a dry place until mixing time.

The fourth step is the actual mixing. The tools needed are shovels, hoes or rakes, a scale, an ordinary sand screen, and a relatively smooth concrete, board, or even hard soil, floor. Usually the materials are spread out in layers. For the 10-20-10 mixture under consideration, a layer of superphosphate may be laid down, next one of uramon, followed by a layer each of tankage and muriate of potash. Preliminary mixing may be done with the hoe or rake. Adding another series of layers in the same

order and mixing may be repeated until all the materials for 1 or 2 tons are laid down. Two men may now turn the materials in such a way as to mix them. Each shovelful should be taken from the floor in order to ensure the maximum of mixing. A steep-sided heap helps, for the materials roll down the side and undergo considerable mixing in doing so. The screen may now be set at a suitable angle and the mixture shoveled through it so as to bring about a maximum of blending. Any lumps that roll off the screen may be crushed with the back of a shovel and put through the screen. If there are few lumps, the fertilizer may be bagged after screening. For more thorough mixing, an additional shoveling may be desirable.

After this shoveling, the fertilizer is ready to weigh back into the bags in which it was delivered. Weighing is not absolutely necessary, but it does aid in the calibration of the drill or in checking the quantity of fertilizer that is being hauled to the field or used on any given acreage.

If mixing is done some weeks before the time for using, the fertilizer should be stored in a dry place away from moist breezes or moist air. If exposure to moist winds cannot be avoided, the pile of fertilizer bags may be protected by a light covering of straw or hay. Keeping the fertilizer dry until seeding time is essential.

Home-mixed fertilizer may not be absolutely uniform, but it is suitable for any ordinary use. Keitt[1] obtained good uniformity by shoveling his materials three times. He found 2.76 pounds of ammonia by analysis in comparison with 2.58 pounds by calculation. Of phosphoric acid, 11.77 pounds were found against 11.84, and 3.01 of potash by analysis in comparison with 3.00 pounds by calculation. The author supervised mixing of fertilizer as a class exercise at Cornell University. The materials were shoveled three times, including screening. The ingredients were provided for a mixture to contain 10 per cent of nitrogen. A sample of the mixture was found upon analysis to contain 10.1 per cent of nitrogen. In both cases, the mixture was entirely satisfactory for every use.

Moreover, the yields of crops which have been fertilized with home-mixed materials have been as good as or sometimes superior

[1] KEITT, T. E., "Chemistry of Farm Practice," p. 164, John Wiley & Sons, Inc., New York, 1917.

to those which have been fertilized with factory-mixed goods. In other words, home-mixed fertilizers that are entirely satisfactory can be made easily.

Advantage and Disadvantages of Home Mixing of Fertilizers.— In the home mixing of fertilizers, a farmer can make any special mixture that may be needed on his soil for his crops. If soil conditions require a fertilizer that will produce an acid residue to aid, for example, in the control of potato scab, he can supply all the nitrogen from sulphate of ammonia and ammophos. The effect of this mixture is definitely acidic. If drier is needed, acid fish may be used.

If neutral or alkaline fertilizer is wanted for lettuce, cabbage, or cauliflower, nitrate of soda, calcium cyanamide, uramon, and animal tankage may be used as sources of nitrogen, and superphosphate and muriate of potash for supplying the other elements. Dolomitic limestone may be used to complete the ton and to ensure neutral or alkaline reaction. Moreover, if one or more of the trace elements is known or believed to be needed, it can readily be included in the fertilizer.

Mixing can be done on many farms in late winter and early spring when little productive work is available. Thus, any saving on home-mixed, as compared with factory-mixed, fertilizer is essentially clear profit. The greatest saving accompanies the mixing of good but relatively inexpensive materials without drier at the time of application. The actual labor of mixing fertilizer does not require much time.

Although the financial saving from home mixing is much less today than it was from 1920 to 1930, it is still substantial. The largest savings, obviously, are made on large quantities of fertilizer. The minimum tonnage on which a worth-while saving can be made is a carload of 20 tons or more, although some saving may be made on 10 tons under favorable conditions such as truck delivery. The latter statement holds, particularly, for mixing for immediate application to the soil.

In contrast, some disadvantages may well be pointed out. Considerable trouble is sometimes encountered in procuring the desired materials in certain areas. No available place on the farm may be suitable for mixing or for storing the fertilizer after it is mixed. It is obviously much less trouble to go to the local fertilizer dealer at planting time for the desired mixed fertilizers

than to home mix them. The large fertilizer manufacturer can use a wider range of materials in his product, including some of the cheaper ones, than can the individual farmer or florist.

On many farms, the advantages outweigh the disadvantages of home mixing. On some farms, including the smaller ones or others that require little mixed fertilizer, the disadvantages may predominate. Home mixing is not advised universally. Often, however, it may pay well to examine carefully the possible benefits of such procedure.

Educational Effects of Home Mixing.—In order to home mix fertilizers intelligently, one must study his soils and crops in order to determine the kind of fertilizer that may be expected to give best results under prevailing conditions. It is essential to know the relative availability of the nutrients in different fertilizer materials, the reaction of the materials, and their residual effect on the acidity or alkalinity of the soil. Moreover, it is essential to know the relative deliquescence of fertilizer materials, their relative value as conditioners, and which materials cannot be safely mixed with certain others. Full information of this sort should be of real service to the user of fertilizers.

THE PURCHASE OF FERTILIZERS

In the purchase of fertilizers, it is important that the fertilizer should supply the nutrients needed and that the nutrients should be of the right availability. Cool-weather crops, for example, need nitrate nitrogen for early-spring growth. Midseason crops can use nitrogen from any source because the soil is warm and nitrification takes place readily and quickly under favorable conditions at that time of year. Because sulphate of ammonia often supplies nitrogen more cheaply than do other ammoniates, much of it is used in regular commercial mixtures. These mixtures, therefore, are well suited for use on high-lime soils for cabbage and cauliflower. For use on acid soils, on which real danger of damage from clubroot on cabbage and cauliflower exists, acid fertilizers are unsuited.

In contrast, fertilizers containing much sulphate of ammonia are well adapted for use on potatoes that are being grown on soils in which danger of scab injury exists. If, however, the acidity of the soil is such that there is no danger of scab injury, a neutral or, better still, an alkaline fertilizer may produce larger yields

than will an acid one. In other words, fitting the fertilizer to the crop and the soil is essential in the purchase of fertilizers.

The purchase of fertilizers for cash is desirable whenever that is possible. Much fertilizer is bought on 3 to 6 months' credit, the dealer or manufacturer acting as banker.

Fertilizer once used cannot be recovered by the dealer as can a plow, wagon, or tractor; and, in part for that reason, ordinary fertilizer-dealer credit comes high. It has recently been as much as 12 to 15 per cent or more on the basis of annual interest. Farmers who have good credit can borrow at the bank, pay cash for fertilizer, and thus save materially on the transaction. By pooling their orders on a cash basis, groups of farmers or individuals often can make savings on their fertilizer purchases that are distinctly worth while.

High-analysis Mixed Fertilizers Most Economical.—Real progress has been made during recent years in raising the plant-nutrient content both of separate carriers and of ready-mixed fertilizers. Only a few years ago, a 5-10-5 fertilizer was regarded as a very high analysis mixture. Double this analysis, or 10-20-10, and even 15-30-15 is now being manufactured. Fertilizers are purchased and used for the actual plant nutrients they furnish to the crop. The 5-10-5 contains 20 units, or 400 pounds, of nutrients to the ton; the 10-20-10, 40 units, or 800 pounds; and the 15-30-15, 60 units, or 1,200 pounds, of actual nutrients to the ton.

Little difference exists in the general charge, or overhead, on a ton of fertilizer whether it be of high or low analysis. Costs of bags, mixing, handling, storage, wear and tear on and depletion of plant, selling costs, and freight are figured largely on the tonnage basis. If the overhead, or fixed charge, is $10 a ton (often it is up to $12), this cost is $0.50 a unit of plant nutrients on the 5-10-5 and $0.25 a unit on the 10-20-10 fertilizer. Moreover, a crop that needs 1,000 pounds to the acre of 5-10-5 may receive the same quantity of nutrients in 500 pounds of 10-20-10. The saving in overhead on this basis (500 pounds of 10-20-10 to the acre), though not great, is $2.50 an acre from the use of 10-20-10 as compared with 5-10-5. Moreover, the higher-concentration goods often contain plant nutrients that are of higher grade than do the lower concentrations. The latter, however, are likely to carry more of the trace elements and others, in addition to nitrogen, phosphoric acid, and potash that may be essential to crops.

At one time, much attention was given to the danger of burning the seed or seedlings as a result of using concentrated fertilizers. Upon further consideration, however, it is quite obvious that actually less soluble salts are used in 500 pounds of 10-20-10 than in 1,000 pounds of 5-10-5. It is mainly the quantity of soluble material that may cause damage. Therefore, actually less damage may be expected from using the higher- than the lower-analysis fertilizers. Long Island potato growers have obtained yields from the use of 10-20-10 as good as or better than those from the same quantity of nutrients in the 5-10-5. Other growers have obtained similar results in widespread experimental comparisons with ordinary-analysis fertilizers. Only half the time is required to haul the fertilizer, and fewer stops are required for filling the drill. The advantages, therefore, are mainly in favor of the higher-analysis fertilizer. On anything approaching a similar pricing basis, all the evidence points to the higher-analysis as the more economical purchase.

THE APPLICATION OF FERTILIZERS

There are numerous ways of applying fertilizers, varying somewhat with the crop for which, and the rate at which, they are used. Superphosphate, rock phosphate, or basic slag for pasture, may be put on with a lime or broadcast fertilizer sower. For such grain crops as wheat, oats, and barley, the fertilizer is usually applied with the fertilizer attachment of the grain drill at the time of seeding. This method of fertilizing small grains was found by Duly[1] in Kansas and by Salter[2] in Ohio to give the best yields.

For vegetable crops, potatoes, and, sometimes, corn, fertilizer is applied near the seed at the time of planting the crop. Much investigational work has been done during the past few years on the specific "placement" of fertilizers in a definite position with respect to the seed.

The Special "Placement" of Fertilizers.—Sayre[3] has reported the results of different ways of fertilizing cabbage over a

[1] Duly, F. L., Methods of Applying Fertilizer to Wheat, *Jour. Amer. Soc. Agron.*, Vol. 22, pp. 1–15, 1929.

[2] Salter, R. M., Forty-seventh Annual Report, *Ohio Agr. Exp. Sta., Bull.* 431, p. 23, 1929.

[3] Sayre, C. B., Comparison of Methods of Fertilizing Cabbage, *New York State Agr. Exp. Sta., Farm Research*, Vol. 5, No. 3, p. 9, 1939.

period of 3 years, 1936, 1937, and 1938, with 600 pounds of 4-16-4 fertilizer to the acre (see Figs. 154, 155, 156, and 157). Drilling the fertilizer on planting day produced an average of 13.35 tons of cabbage to the acre. Placing the fertilizer 2½ inches from the plants in bands on both sides of the row and about 3 or 4 inches below the surface by means of an attachment to the transplanter produced an average yield of 16.35 tons an acre. The increase from side application was 3 tons, or 22.5 per cent

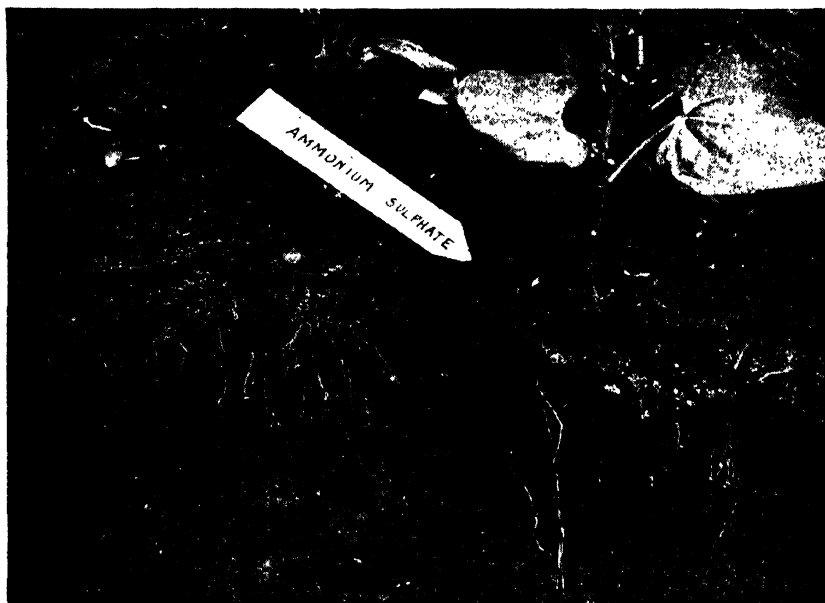



FIG. 154.—Effect of sulphate of ammonia on development of roots of beans. The sulphate of ammonia inhibited root development in the zone ½ inch from the plant on the left. Note the fine development of roots in the soil to the left where no fertilizer was used. The same effects were noted from similar use of other nitrogenous materials with the exception of ammophos and complete fertilizers. (*Courtesy of C. B. Sayre and A. W. Clark, New York State Agr. Exp. Sta.*)

above broadcasting at planting time. Applying the fertilizer with an attachment to the cultivator, 2 to 3 weeks later and 4 inches to the side of the row and 3 inches below the surface, produced an average of 14.56 tons of cabbage. This is an increase of 1.21 tons, or 9 per cent more than is produced by the usual method. In this comparison, the side application at planting time produced decidedly higher yields than the usual method.

Cummings and Houghland have reported the results of 6 years of special fertilizer placement for potatoes in Maine, in New Jersey, on the Eastern Shore of Virginia, on Long Island, in New York, in Michigan, and in Ohio (see Fig. 158). Their data are given in Table 58.

TABLE 58.—EFFECT OF DIFFERENT PLACEMENT OF FERTILIZER WITH RESPECT TO THE SEED PIECE OF POTATOES*

Location of fertilizer with respect to seed piece	2,000 lb.† of single strength, bushels per acre	1,000 lb.‡ of double strength, bushels per acre
Mixed with the soil, largely under seed.....	249	252
Band 4.5 in. wide, 1 in. under seed.........	252	256
Band 2 in. to each side, on seed level.......	279	272§
Band 4 in. to each side, on seed level.......	273	266
Band 2 in. to each side, 2 in. below seed....	275	272

* CUMMINGS, G. A., and G. V. C. HOUGHLAND, Fertilizer Placement for Potatoes, *U.S. Dept. Agr., Tech. Bull.* 669, (facing) p. 30, 1939.

† 4-8-7 used in Maine, New York, New Jersey (5-8-7 in 1931), and 6-6-5 in Virginia (Eastern Shore).

‡ Double the above analyses used.

§ One inch to each side of seed.

Fertilization at 2 or 4 inches to each side and on seed level, and 2 inches to each side and 2 inches below the seed, produced essentially identical yields with both single- and double-strength fertilizers in the Eastern states. Similar placement in Ohio and at both Greenville and Mancelona, Mich., produced the highest yields on the average. Fifteen hundred pounds of 4-10-6 to the acre were used in Michigan, 800 pounds of 4-8-7 in 1931 and 1932, and 800 pounds of 4-12-8 in the other years. Five hundred pounds to the acre was used at Greenville in 1935 and 1937 and at Mancelona in 1935.

Zimmerly[1] has summarized the results of some of the fertilizer-placement studies in the Southeastern states. In Virginia, placement of the fertilizer 2 inches to each side of and on the level of the seed piece gave an increase of 20 bushels of potatoes an acre as an average for 4 years. Similar placement in North Carolina

[1] ZIMMERLY, H. H., Plant Food Developments. *Fertilizer Rev.*, November–December, 1939, pp. 6–7 and 14.

produced 15.2 barrels of potatoes more to the acre than the local method of fertilizing potatoes.

In Virginia, sweet potatoes treated with 1,000 pounds of fertilizer to the acre, placed by the transplanting machine in bands 4½ inches on each side of the row and 3 inches below the surface, produced 43 bushels more potatoes to the acre than did similar

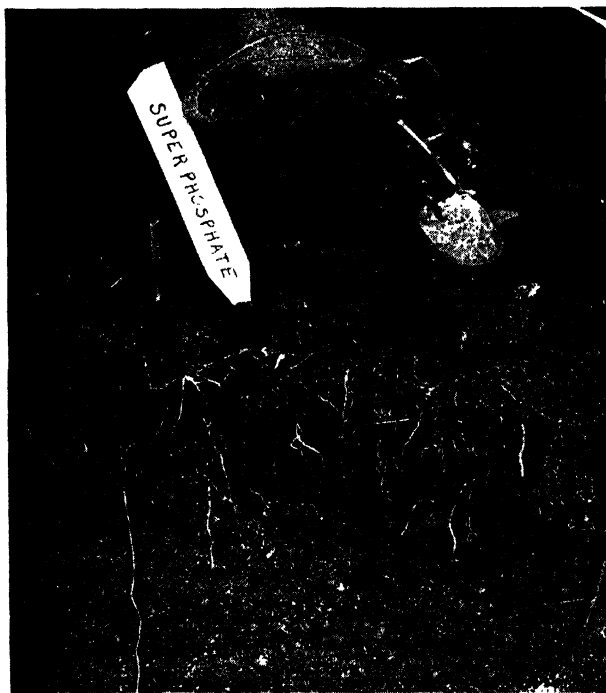



Fig. 155.—Effect of phosphorus on the development of roots of beans. Superphosphate was applied ½ inch to the right of the left-hand bean row. Root development was stimulated in the immediate zone of application. This is in marked contrast to the effect of certain forms of nitrogen. (*Courtesy of C. B. Sayre and A. W. Clark.*)

amounts of fertilizer in the ordinary delayed application. Fertilizing cotton in bands about 3½ inches from and on one or both sides of the row in a number of Southeastern states produced an average of 104 pounds more seed cotton an acre than was grown where the fertilizer was applied and mixed with the soil in a band 3½ inches wide under the seed. In addition, side placement greatly improved the stand of cotton. With tobacco, placement of the fertilizer 2½ inches to each side and 1 inch below the crown

produced $22 worth of tobacco more than did the ordinary fertilization or drilling in the row by hand before ridging the crop.

Work with snap beans shows good results from placing the fertilizer 1½ inches to the side and 1 inch below the seed (Sayre[1]

FIG. 156.—Effect of muriate of potash on the development of roots of beans. Like phosphorus, potash applied ½ inch from the seed had no detrimental effect on root development. Manure salts, however, inhibited root development. (*Courtesy of C. B. Sayre and A. W. Clark.*)

in New York), 2 inches to the side and 2 inches below (Miller and Wright[2] in Louisiana), and 3½ inches to the side and on the level of the seed (Skinner and Serviss[3] in Florida).

[1] SAYRE, C. B., Fertilizer Placement, Experiments with Vegetables at Geneva, New York, *Proc. Nat. Joint Com. Fertilizer Application*, 1936, pp. 39–41.

[2] MILLER, J. C., and R. E. WRIGHT, The Effect of Rate of Placement of Fertilizers on the Growth of Snap Beans, *Proc. Assoc. Southern Agr. Workers*, 1936–1937, pp. 126–127.

[3] SKINNER, J. J., and G. H. SERVISS, Machine Application of Fertilizers to Beans, *Proc. Nat. Joint Com. Fertilizer Applications*, 1933, p. 71.

Sayre and Cummings[1] found that placement of fertilizer for cannery peas about 2½ inches to the side and 1 inch below the seed was best for a 300-pound application of 4-16-4, peas being rather sensitive to fertilizer injury. A 600-pound application

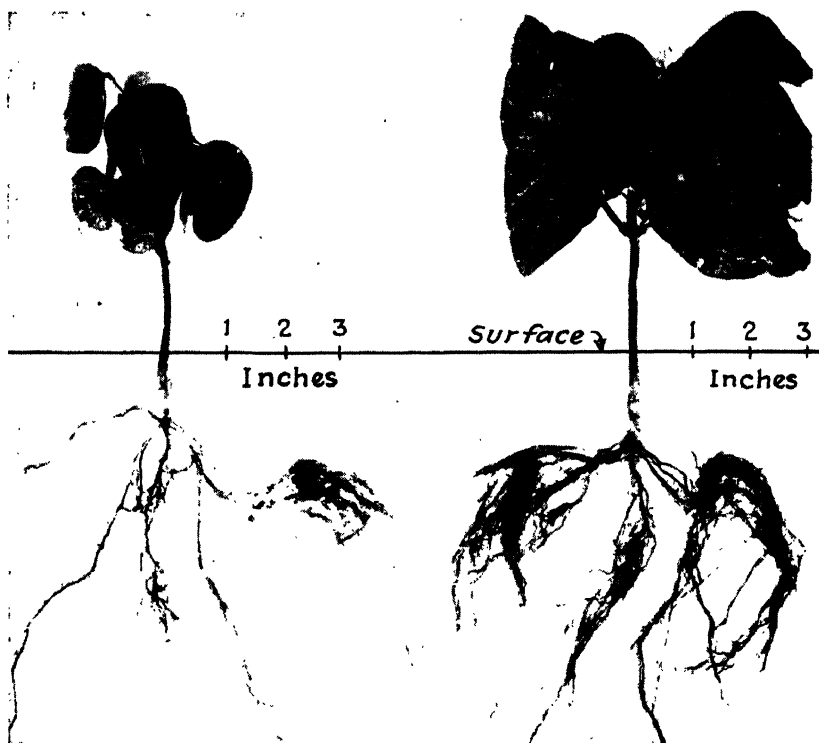



Fig. 157.—Effect of side placement of fertilizer on the root development of beans. A complete fertilizer, 4-16-4, was used. For the plant on the left the fertilizer was placed 2½ inches to the right of the seed. For the right-hand plant the fertilizer was placed in bands 1½ inches from the plant on both sides. The heavy development of roots in the fertilizer zone is notable. Both plants are the same age and the difference in growth is to be attributed to the difference in the placement of the fertilizer. (*C. B. Sayre and A. W. Clark.*)

at 1½ inches to the side, however, gave a slightly higher yield of peas.

Musbach[2] in Wisconsin found that 200 pounds of fertilizer could be applied in the row for peas on heavy clay loams with

[1] Sayre, C. B., and G. A. Cummings, Fertilizer Placement for Cannery Peas, *New York Agr. Exp. Sta., Bull.* 659, p. 7, 1936.

[2] Musbach, F. L., Report of Work on Fertilizer Placement for Canning Peas, *Proc. Nat. Joint Com. Fertilizer Application,* 1937, pp. 161–164.

little injury. A similar application on light soils, however, resulted in injury from the fertilizer.

Preliminary work at five experiment stations indicates that 125 pounds of fertilizer placed in the hill increased the yields of corn as much as, or more than, did 500 pounds to the acre applied broadcast.

Much work is in progress on the placement of fertilizers for vegetables. Many problems remain to be worked out for the

FIG. 158.—The effect of placement of fertilizer on the growth of potatoes in Ohio. The fertilizer was applied in contact with the seed in the center row. The first row to left of center was fertilized in two bands 2 inches from seed piece and on a level with it. Second row to left was fertilized 1 inch under the seed pieces. The row to right of center was fertilized in a band 2 inches under the seed. (*Courtesy of John Bushnell, Ohio Agr. Exp. Sta.*)

various parts of the country. The results from placement are influenced by the crop and its root system, the rainfall during the growing season, the texture of the soil, and the fertilizer and its rate of application.

Additional work is needed before the *best* method can be announced. It may be said, however, that placing fertilizer in bands on one or both sides of the row on a level with, or somewhat lower than, the seed gives excellent results. Although the fertilizer should be placed near the seed, it should not come into actual contact with the seed. Some seeds are much more susceptible than others to injury from contact with the fertilizer.

The Rate of Application.—There are outstanding differences in the rates of application of fertilizers for a single crop under a

great variety of soil, cropping, and market conditions. Among these factors are the cost of fertilizer, the response of the crop to fertilization, the value of the crop, the soils and their previous treatment, and the demand for the product or the outlook for profit from the use of fertilizer (Fig. 159).

Cost of Fertilizers.—A low cost per pound of actual plant nutrients in fertilizers, as compared with a high one or as compared with the price of farm products, encourages the liberal use of fertilizer. Moreover, a relatively low cost improves the chances for profit from the use of the fertilizer on the crop.

FIG. 159.—Effect of quantity of fertilizer on the growth of potatoes in New York. The application on the right was 350 pounds to the acre of 4-8-12; on the left 2,000 pounds of 5-10-5. The yield on the right was 256 bushels. (*Photograph by the author on plots of the Dept. of Vegetable Crops, Cornell Univ. Agr. Exp. Sta.*)

Response of Crops to Fertilization.—Crops vary in their ability to obtain nutrients from the soil. The crops that obtain nutrients from the soil least easily, or that have relatively high requirements, may be expected to respond most to the application of readily available nutrients. Leguminous crops, for example, respond to applications of phosphorus. Most vegetable crops require all of the fertilizer elements on many soils. Nevertheless, some marked variations are found among vegetable crops in this respect. On the basis of extensive experimental work, Hartwell[1] tabulated a number of crops according to their relative response

[1] HARTWELL, B. L., Relative Growth Response of Crops to Each Fertilizer Ingredient and the Use of This Response in Adapting a Fertilizer Analysis to a Crop, *Jour. Amer. Soc. Agron.*, Vol. 31, p. 358, 1921.

to each of the three fertilizer elements. With the thought that Hartwell's grouping may be of interest, it is given here.

TENTATIVE ARRANGEMENT OF CROPS IN ACCORDANCE WITH THEIR INCREASING RESPONSE TO FERTILIZER ELEMENTS; GROUP 3 GIVES GREATER RESPONSE THAN GROUP 1

Group	Increasing nitrogen response	Increasing phosphorus response	Increasing potassium response
1	Rye	Carrot	Corn
	Bean	Buckwheat	Rye
	Corn	Millet	Cabbage
	Cucumber	Oat	Turnip
	Cabbage	Pea	Bean
	Pea	Bean	Oat
	Potato	Tomato	Pea
2	Wheat	Corn	Millet
	Sunflower	Potato	Wheat
	Turnip	Rye	Buckwheat
	Tomato	Wheat	Carrot
	Beet	Sunflower	Potato
	Carrot	Barley	Tomato
	Oat	Lettuce	Barley
3	Millet	Cabbage	Squash
	Parsnip	Beet	Sunflower
	Buckwheat	Cucumber	Beet
	Lettuce	Onion	Onion
	Barley	Parsnip	Parsnip
	Squash	Squash	Lettuce
	Onion	Turnip	Cucumber

Heavier application of the different fertilizer elements, therefore, are justified for the crops that respond markedly, such as those in group 3, than for those whose response is relatively low, such as those in group 1.

Value of Crops.—Crops differ widely in their value per acre. Timothy hay and buckwheat in many sections have a low total value per acre and may be regarded as representing one extreme. Various vegetable and fruit and certain seed crops yield comparatively large cash returns to the acre. Obviously, crops with a satisfactory value per acre can be fertilized much more freely

than the crops that produce relatively low total cash returns to the acre.

Kind of Soil.—At this point, the soil and its treatment require consideration. Sandy and other open soils are less retentive of nutrients, especially nitrogen and to some extent potash, than are the finer grained soils; and they provide relatively little in the way of available nutrients for crops. In contrast, the heavier soils retain nutrients and supply them more generously to crops. Hence, previous fertilization, liming, and manuring may be expected to benefit crops over a longer period of time on heavy than on light soils. Also, residual effects, particularly of nitrogen and organic matter, are more pronounced on the heavy soils.

Outlook for Profit from the Use of Fertilizers.—The outlook for profit from the use of fertilizers is a controlling consideration. If the price of produce is low at planting time and the prospect for an increase slight, the grower may hold fertilizer applications to a minimum. The low-response crops, particularly if they follow a crop that was liberally fertilized the previous season, may well be planted with but little or even with no fertilizer. Instead of a complete fertilizer, the less costly superphosphate alone often may suffice for this type of crop. And the lowest-return groups may be allowed to depend entirely on the residues from previous fertilization.

The crops represented by group 3, especially those whose current price is relatively favorable, are given normal quantities of fertilizer. The crops, however, that are grown on land that has been heavily fertilized and well manured over a period of years may be planted with somewhat less than normal fertilization. It is clear, therefore, that the prospect for profit that prevails at seeding time has a marked influence on the rate of application of fertilizer. Relatively liberal applications, in general, are desirable, especially of available phosphorus in which so many soils are naturally deficient.

Questions

1. What are the various purposes of using fertilizers?
2. What is meant by unit; formula; open and closed, or secret, formula; analysis; mixed fertilizer; complete and incomplete fertilizer; drier, or conditioner; ratio; and guarantee?
3. What is public fertilizer control, and what led to its development?
4. Discuss the advantages of the factory mixing of fertilizers.

5. What are the advantages and disadvantages of home mixing of fertilizers?

6. What is the relative economy of buying high- as compared with low-analysis fertilizer mixtures?

7. Discuss the results of the special fertilizer "placement" studies.

8. How may the design of planting machinery be influenced by the results of placement studies?

9. Outline the factors that govern the rate of application of fertilizers.

10. Give practicable rates of application of fertilizer for the important crops grown in your section.

CHAPTER XVII

THE ROTATION OF CROPS

By *rotation* is meant the growing of crops in a regular order, or sequence, over a period of years. The idea of rotation of crops is not a new one. More or less regular sequence of crops has been observed by the more progressive farmers for many years. As the soils in the United States have been under cultivation longer, the need for and the benefits from following a regular rotation of crops appear to be greater than formerly. A few exceptions may be mentioned. Grasses are, of course, grown on the same land over relatively long periods, but even grasses often produce larger yields during the years immediately after being reseeded. Potatoes are being grown over a period of years on the same land. How long this practice can be continued without encountering some difficulty has not yet been determined. Practicing a regular rotation of crops, however, does possess real advantages.

Advantages of Rotation of Crops.—The advantages that may be derived from following a regular rotation of crops are here discussed under seven headings. Obviously, some of them are more important than others, and some are more important in one locality or in one type of farming or in one sequence of crops than in others.

Uniform Acreage of Each Crop Every Year.—If a farm consists of the same number of fields (or a multiple of that number) as of years in the rotation and the fields are of approximately uniform size, it is an easy matter to grow about the same acreage of all the crops in the rotation every year. In the case of strip cropping land, the strips cannot be of absolutely uniform size because of variations in the topography of the land on most farms. It has been the author's observation, however, that by the exercise of some ingenuity on the part of the farmer and the planner a reasonable degree of uniformity in acreage of each crop can be maintained even on strip cropped land.

The need for cash crops and for grain and roughage for livestock is much the same from year to year. For this reason, therefore, a uniform acreage each year is highly desirable. Furthermore, a uniform acreage of each crop each year furnishes a similar period of employment to the farm help. Full employment of labor throughout the year is ideal, and a regular rotation of crops aids somewhat in its attainment.

Improved Control of Weeds.—Some weeds thrive in association with certain crops but not with others. In the Midwest, for example, the perennial morning-glory, or black bindweed, thrives in corn that is grown on productive soils. The tillage required for corn favors this weed. A thick, thrifty meadow of grass and red clover or alfalfa, in contrast, competes successfully with the bindweed for their common requirements, light, moisture, and plant nutrients. However, myriads of other weed seeds germinate in the corn and are killed by cultivation. Of itself, this helps reduce the number of live weed seeds in the soil and thus aids in their ultimate control.

In the Northeastern states, certain weeds thrive in meadows but not in cultivated crops such as corn, beans, cabbage, or potatoes. Examples of these weeds are the oxeye daisy, golden rod, and devil's paintbrush (or hawkweed). The thrifty growth of these weeds in meadows casts doubt upon the feasibility of strictly *all-grass* farming in these states. Occasional plowing and reseeding are essential for effecting a reasonable degree of control of these perennial meadow weeds.

A regular rotation with its recurring clean-tilled crops and grains and legumes and grasses that serve as smother crops, aids materially in weed control.

Improved Control of Insects and Plant Diseases.—In areas where the European corn borer, for example, has become established, infestation is likely to be greatly increased by growing two or more successive crops of corn on the same field, particularly if control measures are neglected. Some care is needed in order to avoid other crops on which this pest lives and multiplies. Rotating corn with crops that do not serve the borer as a breeding and feeding place, therefore, aids in its control.

If cabbage or other cruciferous crop is grown often on soil in which clubroot thrives, the soil becomes badly infected with the clubroot organism. Unless extremely heavy liming is practiced

or such crops as cabbage and cauliflower are not grown on this infected soil for a long period of years, members of the cruciferae group are subject to severe reduction in yield. Following a sequence of crops that does not bring corn or a crop of the cabbage family onto the soil at too short intervals aids materially in the control of the corn borer on the one hand and of clubroot on the other. These are merely illustrations of the necessity for rotating certain crops rather than growing them on the same land for some years in succession or at too short intervals.

Potatoes appear in some respects to be an exception. Wireworms do not infest land that grows potatoes year after year. They live and multiply in grains and grasses, but the insect appears not to tolerate legumes. Potatoes might be grown in a rotation with legumes in which grasses are not sown. Potatoes adequately fertilized can be grown year after year on the same land with good yields. It seems probable, however, that the introduction of legumes may ultimately prove beneficial. On rather steeply sloping lands, it may be essential to admit both grass and grain in a compromise between complete control of the wireworm and no control of losses of water and soil. The problem of potato scab, however, must not be overlooked in connection with growing legumes in rotation with potatoes.

Improved Distribution of the Root Systems of Crops.—Crops vary in the depth of their root systems, some being near the surface and others at a greater distance from it. Obviously, each crop draws its supply of nutrients from the soil in its own root zone. Shallow-rooting crops tend to deplete the nutrients in the immediate surface soil. It is desirable, therefore, that deeper rooting crops follow shallow-rooting ones. The former obtain nutrients from a lower zone that has not been depleted even temporarily by the preceding crops. Alternating deep- with shallow-rooting crops consequently may produce larger yields than does growing either deep- or shallow-rooting ones continuously.

Improved Maintenance of Organic Matter.—Some crops, such as the intertilled ones, tend to deplete the soil of organic matter. In contrast, legumes and grasses do not deplete the soil so rapidly as do intertilled crops. And some legumes, such as the biennial and perennial ones, along with grasses may build up the supply of organic matter in the soil. A rotation of crops that provides for grain, clover, and grasses following intertilled crops, such as

corn or potatoes, aids greatly in maintaining the supply of active organic matter in the soil. This is especially true in contrast to the depleting effect on organic matter of growing clean-cultivated crops for several years in succession.

Improved Tilth.—Soils that grow clean-tilled crops continuously, in part because of the loss of organic matter, tend toward a poor physical condition or one of poor tilth. In this condition, percolation, aeration, and nitrification are retarded, and as a consequence the growth of crops is diminished. The small grains produce root systems that permeate the surface soil, leave some organic matter in it, and as a result improve conditions for other crops. Legumes or mixtures of legumes and grasses add some nitrogen to the soil. And their roots, particularly those of grasses, thoroughly permeate the soil in their root zone. In doing this, the roots aid in the production of the granular condition that is characteristic of timothy or other meadow sods. The excellent tilth of such a sod is in marked contrast to the condition of the same soil that has grown clean-tilled crops for several years in succession.

Increased Crop Yields.—In comparison with growing corn or oats continuously over a period of years, rotating them with legumes and grasses increases yields. The improvement in yields as a result of rotating crops is well shown in the experiments that have been conducted over different periods of time at several experiment stations. Representative data from a few of them are given here. Thorne's data on the effects of rotation on yields of corn, oats, and wheat in Ohio are given in Table 59.

Except on corn, the percentage increases that resulted from rotating these crops without fertilization were marked. The effects of rotation on yields of crops that received nitrogen, phosphorus, and potash were not very large except on oats; this was 52 per cent. Rotation more than doubled the yield of manured corn and increased the yield of oats by almost 70 per cent. The yield of manured wheat, however, was slightly lower in rotation than when grown continuously. In spite of a few instances of only small increases (3.0 per cent loss on wheat), the average increase for the three crops for the three conditions was 50 per cent.

In Table 60 are given the yield data from continuous corn as compared with the corn year of the corn and oats and the

corn, oats, and clover rotations at the Illinois Experiment Station.

TABLE 59.—EFFECT OF ROTATION AS COMPARED WITH CONTINUOUS CROPPING OF CORN, OATS, AND WHEAT* (1914–1923)†

Crop	Treatment	Yield, bushels		Increase	
		Continuous	Rotation‡	Bushels	Per cent
Corn............	None	15.9	19.0	3.1	19.5
	N—P—K	33.3	45.6	12.3	36.9
	Manure	17.8	37.5	19.7	110.7
Oats............	None	17.6	29.7	12.1	68.7
	N—P—K	37.0	56.3	19.3	52.2
	Manure	25.4	42.7	17.3	68.1
Wheat..........	None	6.8	11.4	4.6	67.6
	N—P—K	19.3	25.2	5.9	30.6
	Manure	15.5	14.9	....	−3.0

* THORNE, C. E., The Maintenance of Soil Fertility, *Ohio Agr. Exp. Sta., Bull.* 381, pp. 300–315, 1924.

† These data are for the third decade of the 30 years reported in this publication.

‡ Rotation, corn, oats, wheat, clover, timothy. Treatment was identical on these crops, continuous and rotated.

This experiment has been carried on continuously since 1879. Yield data have been taken for 50 years. Originally, one plot produced corn continuously, on another corn was alternated with oats, and on a third corn was grown in rotation with oats and clover, all without treatment. In 1904, the plots were divided and treatment with manure, limestone, and rock phosphate begun. The data in Table 60 are averages of the six-crop movable averages for the years 1925, 1931, and 1937 in which all the plots were growing corn.

The corn and oats rotation increased the yields over continuous corn, 36.5 per cent on untreated and 40.6 per cent on the treated soil. The corn, oats, and clover rotation raised the yield over continuous corn production 82.4 per cent on untreated and 50.9 per cent on the treated soil.

As in the Ohio work, rotation including clover in Illinois was distinctly effective in helping to maintain crop yields.

The results from Ohio and Illinois are used because of the long period over which these experiments have been carried on. In

Ohio, the experiment had been running for 2 decades previous to the 10-year period covered by the data in Table 59. This appears to have been an ample period for the effect of rotating crops to be fully reflected in the yields. The Illinois work has been going on for 60 years including the 1939 crop. Yield data with no change in the untreated plots are available for 52 years.

TABLE 60.—EFFECT OF ROTATIONS ON YIELD OF GRAIN IN COMPARISON WITH CONTINUOUS CORN IN ILLINOIS*

Cropping condition	Treatment	Yields, bushels	Increase in yield due to rotation, bushels	Increase over continuous corn, per cent
Continuous corn........	Untreated	23.3		
	Treated	41.6		
Corn and oats..........	Untreated	31.7	8.4	36.5
	Treated	58.5	16.9	40.6
Corn, oats, and clover...	Untreated	42.5	19.2	82.4
	Treated	62.8	21.2	50.9

* BAUER, F. C., of the Illinois Agr. Exp. Sta., unpublished data in a personal communication, 1938.

Development of the Rotation.—Rotations are developed around the leading crop and one or more legumes and grasses. The leading crop is often, although not always, a clean-tilled one, since it is the cash, or the principal feed-grain, crop. In this situation it is natural and desirable that a small-grain crop should follow the clean-tilled one. Sometimes the grain can be grown on the residue from the fertilizer that was applied for the clean-tilled crop. This is true particularly if the latter was heavily fertilized. Clover or other legumes and grasses are seeded in or following the grain crop, with little or no additional cost for seedbed preparation. In the case of meadows the crop is largely clover the first year and largely grasses the second and additional years.

In a livestock system of farming, the grass may be harvested over several years if the stand remains good and if yields are maintained. If the clean-tilled crop is relatively the most important, the rotation might be held to 3 years, the clover or the clover

aftermath being turned under for the clean-tilled crop. If the hay and the clean-tilled crop are of similar importance, hay may be made for 1 or 2 years after clover, depending on the requirements for roughage.

More organic matter is lost during the year in which the clean-tilled crop is grown than in any other year. Greater danger of erosion exists during this year than in the other years of these rotations. Small grains conserve organic matter, water, and soil to fair advantage. Clover and other legumes fix nitrogen under favorable conditions. And if the hay is fed on the farm and the manure conserved and returned to the soil, legumes may temporarily increase its organic-matter and nitrogen content. Both clover and grasses hold water, and good stands of them control erosion. Moreover, some nitrogen may be added to the soil by nonsymbiotic soil organisms during the period in grass.

In addition, grasses, by means of their fibrous root systems which permeate good soils, improve the tilth of the soil to a marked extent. This is generally recognized when a timothy or bluegrass sod is plowed for a clean-cultivated crop. The effects of rotations of this general character may well be expected to produce the results given in Tables 59 and 60.

Practicable Rotations.—A wide range of excellent rotations is available and is, in fact, being followed in places throughout the country. Closer adherence to a definite sequence of crops than is being practiced in some parts of the country is desirable. It is a good feature of the best rotations that every crop grown should possess a fairly high money value or else leave the soil in an improved condition for production of the higher paying crops. Good, representative rotations are given for a number of regions in this country.

Corn Belt.—A rotation of corn, oats, and clover is used on a large acreage in the Corn Belt. Corn, corn, oats, and clover may be even more commonly grown than corn, oats, and clover. Winter barley or wheat may be substituted to advantage for oats in some sections. Corn, soybeans, wheat or winter barley, and clover constitute a desirable rotation in that it contains two legumes. Soybeans often add little nitrogen to the soil, but they improve the tilth of some soils. Sweet clover for pasture, seed, or green manure may be used under certain conditions in place of the usual red clover. From the standpoint of reducing wash-

ing of the soil during winter and spring, winter barley possesses a distinct advantage over spring-sown oats.

For Missouri, Etheridge and Helm[1] recommend a rotation of corn, oats, and wheat in which Korean lespedeza has been established. In like manner, oats, wheat, winter barley, and rye may be grown in rotation, the lespedeza being established in this soil.

Once established, Korean lespedeza is a self-seeding, nitrogen-gathering catch crop. This desirable arrangement of crops may be expected to build up the organic and nitrogen content of the soil.

Great Plains.—Laude and Swanson[2] recommend a 4-year rotation of sorghum, barley or oats, and wheat the third and fourth years for central Kansas. Salmon and Throckmorton[3] reported corn, corn, oats, sweet clover, and wheat to be a popular rotation in eastern Kansas. On farms that require clover hay, a better arrangement is corn, corn, oats, wheat, and clover. On the thinner soils, more legumes are included. Such a rotation is corn with lespedeza seeded, oats, sweet clover, wheat, and red clover, the fifth year. The growing of legumes in 2 out of 5 years with volunteer lespedeza for the other years should adequately maintain the nitrogen and organic supply for these crops.

Hay and Pasture Area.—In the hay and pasture area of the Northeastern states, a 4-year rotation is followed somewhat commonly. This rotation consists of corn, oats or barley or a mixture of them, clover, and timothy. Under conditions favorable for timothy and other hay grasses, particularly if manured, the grass may be harvested for some additional years thus making the rotation one of 5, 6, or 7 years instead of 4. Potatoes, dry and snap beans, cannery peas, or cabbage are substituted for corn on a part of the acreage on many farms that are favorably situated with respect to soil and markets.

Another rotation that is followed to a considerable extent is one of 5 years, corn, oats, wheat, clover, and timothy. On soils

[1] Etheridge, W. C., and C. A. Helm, Korean Lespedeza in Rotations of Crops and Pastures, *Missouri Agr. Exp. Sta., Bull.* 360, pp. 6–12, 1936.

[2] Laude, H. H., and A. F. Swanson, Sorghum Production in Kansas, *Kansas Agr. Exp. Sta., Bull.* 265, pp. 39–40, 1933.

[3] Salmon, S. C., and R. I. Throckmorton, Wheat Production in Kansas, *Kansas Agr. Exp. Sta., Bull.* 248, pp. 11–17, 1929.

adapted for it, alfalfa may be substituted for or mixed with clover for the leguminous hay year of the rotation. This use of alfalfa is advantageous because ordinarily the yield and feeding value of the second-year hay is thereby materially improved.

Cotton Belt.—A wide variety of rotations that include cotton is found in the Cotton Belt. Only a few examples can be given here. Alexander recommends particularly interesting rotations in Georgia.[1] Two have been selected from the rotations suggested, a cotton-corn-forage and a cotton-corn rotation.

The cotton-corn-forage rotation covers 3 years. In the first year, cotton is followed by a winter legume and small grain. In the second, the winter legume and small grain are grazed off or cut for hay and followed by a summer legume for forage which, in turn, is followed by a winter legume. In the third year, the winter legumes are plowed down and followed by corn.

The cotton-corn rotation consists of cotton the first year, followed by a winter legume. The second year, the winter legume is plowed under, and corn is interplanted with a legume. In the fall, the soil is plowed and prepared for cotton the following year.

These rotations are characterized by frequent recurrence of legumes. This of itself aids greatly in maintaining the productivity and the organic content of the soil. In addition, the soil is seldom exposed to erosion for any length of time during these rotations.

Northern Wheat Belt.—In South Dakota, Hutton[2] reported data from growing one rotation of corn, oats, wheat, barley, and red clover and another that is very similar, namely, corn, wheat, barley, oats, and red clover.

The contrast with respect to legumes between these rotations and those of Alexander in Georgia is great. One must remember, however, that variations in length of growing season, precipitation, and soil conditions also are great. As the country grows older and the need for additions of organic matter becomes more acute larger use of legumes appears desirable.

One point to be borne in mind, however, is that legumes generally use large quantities of water. In an area such as the

[1] Alexander, E. D., Austrian Winter Peas and the Vetches, *Georgia Agr. Exp. Sta., Bull.* 453, pp. 19–24, 1935.

[2] Hutton, J. G., Thirty Years of Soil Fertility Investigations in South Dakota, *South Dakota Agr. Exp. Sta., Bull.* 325, 1938.

Great Plains, water is of primary importance. Crops, therefore, that may deplete the water supply even of the subsoil cannot be used so freely as in the humid regions, for reducing the water supply may lower the yield of the more important crops.

Questions

1. What is meant by rotation of crops?

2. Discuss the advantages of rotating crops.

3. Under what conditions is rotation not essential or even impossible?

4. What determines the place of different crops in a rotation?

5. Outline a practicable rotation of the important crops grown in your locality.

CHAPTER XVIII

THE FERTILIZATION AND THE LONG-TERM MAINTENANCE OF THE PRODUCTIVITY OF MINERAL SOILS

Fertilization for the maintenance of a high degree of productivity of mineral soils over the long term is a problem of great import, next, in fact, to that of holding the soil itself in place (Chap. IX). During the life of the known deposits of phosphates and of potash salts, these fertilizer materials can be returned to the soil; but if the body of the soil is washed away, it is all but gone forever.

Productivity Lowered by Cropping.—Considerable information has accumulated over the past half century to the effect that soils long cropped without the regular return of plant nutrients have been depleted in productive power (Fig. 160). It is true that lower yields are obtained in spite of all the advancements that have been made during this period. Among the advances made are higher yielding strains and improved varieties of many crops, improved control of insects and plant diseases, improved implements for tillage, seeding, and harvesting, and the introduction of new crops. A favorable combination of all of these conditions has failed to counteract the slow but steady long-term depletion of the soil. As depletion of nutrients or organic matter proceeds on sloping lands the loss of soil material itself tends to become more and more rapid. And along with the loss of soil goes the loss of organic matter and the more readily available nutrients that occur largely in the fine surface-soil material. The more the soil is depleted the easier it washes, and washing increases the rate of depletion of nutrients. Both forms of soil deterioration reduce crop yields. And reduced yields, in turn, result in diminished protection of the soil. In addition, lowered yields result in smaller amount of residues going back into the soil for the benefit of succeeding crops and for improvement in tilth and, consequently, for control of the early stages of erosion.

All these factors emphasize the intricate interrelationships and their bearing on crop growth and the productivity of the soil.

Long-term experimental work in the fertilization of crops on different soils has been in progress for many years. The work in Illinois, Pennsylvania, Ohio, and Missouri appears to be the oldest in the order named.

George E. Morrow started the work on what have been called the Morrow plots at Urbana, Ill., in 1879. Of the seven original plots, four have been discontinued owing to the encroachment

Fig. 160.—Soil depletion. The growth of clover on the pot with "No treatment" represents the depleted condition of this soil (Lordstown stony silt loam in New York). Phosphorus and potash stimulated growth only very slightly. Limestone in addition to phosphorus and potash produced a fine growth of clover. The omission of potash in the fourth pot lowered the yield slightly and limestone and potash with no phosphorus failed to make nearly as good growth as with phosphorus. (*Photograph by the author, Cornell Univ. Agr. Exp. Sta.*)

of the University buildings. The other three have been continued to the present time (1940), a period of 61 years. Records of the yields have been kept since 1888. More extensive work was begun on the Davenport plots in 1902 and on the South Farm in 1903 by the late Cyril G. Hopkins.

The plot work at State College, Pa., begun by W. H. Jordan, was laid out in 1881, only 2 years after Morrow started his work in Illinois. Jordan's plots were by far the more extensive of the two. In Ohio in 1893, Charles E. Thorne started extensive fertilizer, manure, and rotation studies. Important pioneer work at the Missouri Agricultural Experiment Station was begun soon

after that in Ohio. The New Jersey, South Dakota, and Iowa experiment stations and many others for shorter periods have engaged in one or more phases of soil experimental studies, includ-

TABLE 61.—RESULTS OF 30 YEARS OF SOIL TREATMENT WITH MANURES AND FERTILIZERS IN OHIO*

Crop	Treatment	1894–1898	1899–1903	1904–1908	1909–1913	1914–1918	1919–1923
				Continuous cropping			
Corn	None	29.1 bu.	21.8 bu.	17.1 bu.	15.8 bu.	16.4 bu.	15.4 bu.
	N—P—K	44.6 bu.	47.2 bu.	38.5 bu.	36.4 bu.	33.7 bu.	32.9 bu.
	Manure†	36.4 bu.	29.2 bu.	23.8 bu.	18.9 bu.	18.7 bu.	16.9 bu.
Oats	None	26.9 bu.	16.8 bu.	20.4 bu.	15.5 bu.	21.3 bu.	13.9 bu.
	N—P—K	42.2 bu.	40.1 bu.	45.5 bu.	34.5 bu.	43.0 bu.	30.9 bu.
	Manure	30.8 bu.	36.5 bu.	35.0 bu.	26.1 bu.	28.8 bu.	22.0 bu.
Wheat	None	10.6 bu.	7.8 bu.	5.6 bu.	5.1 bu.	8.3 bu.	5.2 bu.
	N—P—K	19.8 bu.	21.9 bu.	17.4 bu.	17.3 bu.	22.3 bu.	16.4 bu.
	Manure	13.3 bu.	14.3 bu.	12.2 bu.	14.9 bu.	17.7 bu.	13.4 bu.
			Crops in rotation—corn, oats, wheat, clover, timothy				
Corn	None	31.9 bu.	32.9 bu.	26.9 bu.	19.1 bu.	19.4 bu.	18.5 bu.
	N—P—K	35.8 bu.	49.5 bu.	50.6 bu.	41.5 bu.	41.6 bu.	49.6 bu.
	Manure‡	38.9 bu.	43.1 bu.	45.8 bu.	35.0 bu.	39.5 bu.	35.5 bu.
Oats	None	32.2 bu.	28.3 bu.	36.8 bu.	27.8 bu.	38.0 bu.	21.4 bu.
	N—P—K	38.0 bu.	49.2 bu.	55.4 bu.	49.9 bu.	62.0 bu.	50.7 bu.
	Manure	32.4 bu.	36.5 bu.	41.6 bu.	34.8 bu.	48.2 bu.	37.2 bu.
Wheat	None	8.8 bu.	9.0 bu.	12.7 bu.	11.5 bu.	13.7 bu.	9.2 bu.
	N—P—K	13.8 bu.	23.2 bu.	28.4 bu.	22.0 bu.	29.0 bu.	21.4 bu.
	Manure	11.5 bu.	14.7 bu.	23.7 bu.	20.6 bu.	11.5 bu.	18.3 bu.
Clover	None	1,377 lb.	1,769 lb.	1,881 lb.	1,578 lb.	898 lb.	1,069 lb.
	N—P—K	2,590 lb.	2,176 lb.	4,557 lb.	3,193 lb.	2,737 lb.	3,680 lb.
	Manure	2,550 lb.	2,285 lb.	3,830 lb.	2,809 lb.	2,347 lb.	2,391 lb.
Timothy	None	2,553 lb.	2,498 lb.	3,103 lb.	2,853 lb.	2,034 lb.	2,076 lb.
	N—P—K	2,800 lb.	2,552 lb.	4,567 lb.	4,058 lb.	4,529 lb.	4,135 lb.
	Manure	3,370 lb.	2,730 lb.	4,714 lb.	4,124 lb.	3,719 lb.	4,263 lb.

* THORNE, C. E., The Maintenance of Soil Fertility, *Ohio Agr. Exp. Sta., Bull.* 381, pp. 300–315, 1924.
† At rate of 2½ tons an acre a year.
‡ Four tons each for corn and wheat and 8 tons each for clover and timothy.

ing rotations and the utilization of farm manure. The experimental soil work in Ohio and Illinois has been selected for more extended consideration. The results of 30 years of experimental work in Ohio are given in Table 61.

The fertilization consisted of 160 pounds of superphosphate and 100 pounds of muriate of potash a year on each of the three crops, corn, oats, and wheat, that were grown continuously. In addition, corn and oats each received 160 pounds of nitrate of soda, and wheat, 120 pounds of nitrate of soda and 50 pounds of dried blood an acre a year. The treatments with nitrogen amount to the equivalent of approximately 500 pounds an acre a year of a fertilizer carrying 5 per cent of nitrogen. The phosphorus is equivalent to that in about 300 pounds of a fertilizer carrying 15 per cent of phosphoric acid, and the muriate of potash applied, to the potash in 1,000 pounds of fertilizer that contains 5 per cent of potash.

These rates of application are liberal, with the exception of phosphorus. Their effects on the yields of these crops throw much light on what may be expected in the way of long-term trends with respect to yields under continuous cropping.

Corn, oats, and wheat when grown continuously without fertilization went down in yield rather rapidly during a period so short even as 30 years. The yields of all three crops, as an average of the last 5 years, were in general only one-half the yield of the first 5 years in this period of 30 years. Even with the complete fertilization given annually, yields dropped significantly. An annual application of 2½ tons of manure an acre produced less than one-half as much corn and about three-quarters as much oats to the acre during the last as compared with the first 5-year period of this experiment. Continuous cropping over three decades in Ohio resulted in decided reductions in the yields of corn, oats, and wheat with one exception: manure appears to have maintained the yield of wheat.

In comparison, these three crops in addition to clover and timothy were grown in a rotation of 5 years under these conditions: (1) There was no treatment whatever. (2) There was complete fertilization consisting of 160 pounds of 14 per cent superphosphate each on corn, oats, and wheat; 80 pounds of muriate of potash on corn and oats, and 100 pounds on wheat; and 80 pounds of nitrate of soda each on corn and oats and wheat, slight changes in rates of application being made in the early years of the experiment. (3) Four tons of barnyard manure an acre were put on for both corn and wheat, and 8 tons each on clover and timothy in the rotation. The fertilizer nitrogen

treatment given was equivalent approximately to that in about 750 pounds of 5-15-5 fertilizer, the phosphorus to that in 450 pounds of 5-15-5, and the potash to that in 2,600 of 5-15-5 during the 5-year rotation.

Comparisons of the 5-year average yields during the first and final periods of the 30 years covered by these experiments are indeed interesting. Yields of each of the grains held up better with no treatment under rotation than in continuous cropping, as would have been expected. Wheat, however, held to an essentially stationary yield under rotation. Yields of untreated clover and timothy fell off even under rotation.

These data show definitely that this rotation alone cannot maintain yields of corn and oats under Ohio conditions. All the grain yields were increased markedly in rotation by applications of fertilizer nitrogen, phosphorus, and potassium, as also were those of clover and timothy.

An application of 4 tons of manure each for corn and wheat and 8 tons each on clover and timothy increased the yields of oats and wheat slightly and the yield of timothy materially. Yields of manured corn and clover, however, were both lower during the final period than in the initial one. Both these crops have a fairly high requirement of phosphorus, and this may explain the failure of manure to maintain the yields of these crops throughout the 30-year period of the experiment.

TABLE 62.—CORN YIELDS AS SIX-CROP MOVABLE AVERAGES, MORROW PLOTS, ILLINOIS AGRICULTURAL EXPERIMENT STATION*

Year	Continuous corn		2-year periods				3-year periods			
			Continuous corn		2-yr. rotation		Continuous corn		3 yr. rotation	
	Untreated, bu.	Treated, bu.	Untreated, bu.	Treated, bu.	Untreated, bu.	Treated, bu.	Untreated, bu.	Treated, bu.	Untreated, bu.	Treated, bu.
1907	31.4	36.6	32.3	36.7	43.1	48.9	29.9	32.4	54.6	59.7
1913	26.7	40.3	24.6	33.5	37.4	50.7	29.9	37.7	52.7	64.2
1919	26.7	43.2	28.6	45.2	36.5	60.8	23.5	34.4	51.4	68.1
1925	22.4	41.8	26.3	49.2	33.8	63.9	22.4	37.6	43.9	61.1
1931	20.9	37.5	20.4	40.9	26.9	58.9	21.0	36.8	43.5	61.1
1937	26.5	45.5	31.9	50.5	34.8	52.6	29.9	55.9	40.2	66.1

* BAUER, F. C., data supplied in a personal communication.

The yields from the Morrow plots in Illinois are given in Table 62.

It is recognized that this, in common with much of the older, work is open to criticism because of lack of replication. Its long-term character, however, appears to warrant giving it some consideration. An average of the six-crop movable averages for 1888, 1889, and 1890 was 50.6 bushels of shelled corn to the acre on this brown silt loam. An average of the six-crop averages covering the 12 years 1928 to 1937 was 22.0 bushels of corn to the acre. In other words, the loss in yield of corn was 60 per cent over a period of 44 years (1889 and 1933 are the median years in these averages of six-crop averages). This is indeed a severe drop in yield even for continuous corn on so rich a soil as this one. In contrast, during the comparable years of corn in a rotation of corn and oats the yield was 28 bushels of shelled corn. This increase of 6 bushels an acre may be attributed to the beneficial effects of alternating oats with corn. Untreated corn during the years when this crop occupied the soil on which corn was grown in rotation with oats and clover (since 1902) produced 41.8 bushels. This increase of nearly 20 bushels to the acre may be credited to clover and rotation. Since oats raised yields 6 bushels, the remaining 14 bushels of the increase may be attributed to the effects of clover and this rotation (see Fig. 161).

In 1904, the three plots were divided; and limestone, manure, and rock phosphate were applied to subplots. During the ensuing 34 years, this treatment increased the yield of continuous corn to 45.5 bushels an acre as the six-crop movable average for 1937. This treatment, therefore, more than doubled the yield. In the 2-year rotation, the yield was 52.6 bushels and in the 3-year rotation 66.1 bushels to the acre on the fertilized land. In the 2-year rotation, the treatment restored the yield to substantially that of 50 years earlier. Following the 3-year rotation with the same treatment since 1904 increased the yield of corn to more than 30 per cent above the yield produced 50 years earlier.

Space, unfortunately, does not permit of detailed discussion of additional results of soil-fertility experimental work. Based on this long-term work in Ohio and Illinois, the following conclusions appear to be warranted: (1) Yields of grain fall off rapidly under continuous cropping without treatment over a period of 30 to 50 years. (2) Alternating corn and oats resulted in a

marked loss in yield of corn, but substantially less than from growing corn continuously. (3) Over a period of 34 years, the yield of corn grown in rotation with oats and clover without fertilization dropped approximately only one-fifth, or 20 per cent. (4) The return of nutrients (in manure, limestone, and rock phosphate) doubled the yield of continuous corn, increased it in rotation with oats to a marked extent, in fact, restored the yield

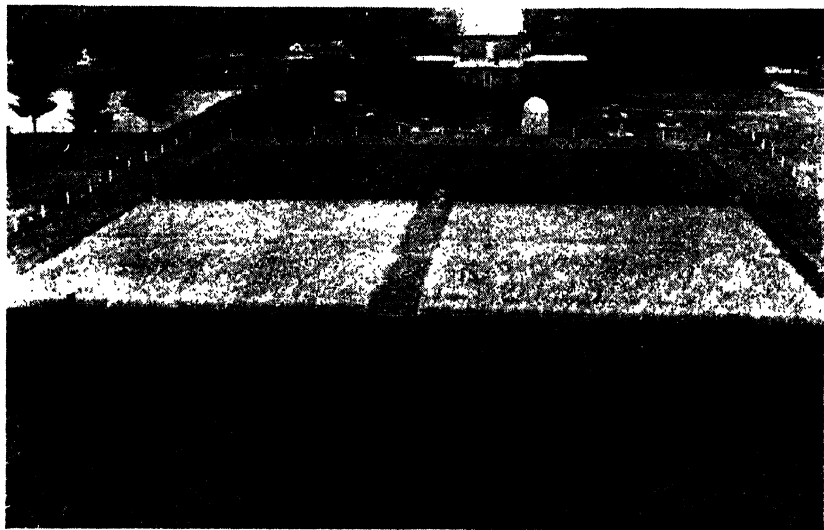



FIG. 161.—Morrow plots at the University of Illinois. The corn plot in the background has grown corn continuously for 65 years including 1940. The plot in the middle is in oats that have been alternated with corn, and the clover in the foreground is being grown in rotation with corn and oats. The nearer or south half of each plot has been treated with limestone, manure, and rock phosphate during recent years. The small growth of corn in the extreme background indicates the extent of depletion of this untreated soil cropped continuously to corn. (*Courtesy of F. C. Bauer, Agronomy Dept., Illinois Agr. Exp. Sta.*)

of corn to that at the beginning of the experiment, and, in rotation with oats and clover, not only restored the corn yield but increased it by more than 30 per cent above the original yield of corn. It is interesting to know that originally productive, but depleted, soils can be restored to, or raised above, their original productivity by simple and relatively inexpensive treatments. It should be added, however, that this increase was accomplished on soils the depletion of which was not accompanied by serious loss of soil and nutrients by washing.

The "Quick" Chemical Soil Tests.—"Quick" chemical tests have received much attention during recent years. The idea of determining the approximate quantity of more or less "available" phosphorus is not a new one, dilute acids having been used for this purpose for some years. Recently a large number of "quick" tests have been widely used for estimating the amount of each fertilizer element to the acre that is available.

The test used by Morgan[1] may be cited to illustrate the general type of procedure. He uses a mixture of acetic acid and sodium acetate of approximately 0.5 normal acidity which is buffered at a pH of 4.8. The extracting solution is passed through the soil; or the soil is placed in the solution, shaken, and filtered. The filtered solution is the soil extract that is tested for the various fertility elements. In view of the fact that a very small quantity of soil is used, great care is required in sampling in order that the sample may be representative of the soil from which it was taken. Soils are found to be "high," "medium," or "low" in the various constituents, these designations being based on arbitrary standards.

Tests of this nature are subject to limitations under many soil and cropping conditions. Much information in addition to that supplied by the test is needed as a basis for recommending the fertilization that should be given to the soil for a specified crop. Moreover, quite aside from the results of the test, consideration must be given to such factors as those mentioned on page 359 as governing the quantity and kind of fertilizer that may be used with profit by the farmer.

In Hawaii, "quick" tests are used in connection with greenhouse and field fertilizer trials with sugar cane. In many instances, the quantity of fertilizer used is reduced as a result of the tests; and this saving justifies considerable expenditures for testing and experimental work.

The Maintenance of Adequate Calcium for Legumes.—Legumes in comparison with nonlegumes require fairly large supplies of active calcium. Usually, a supply of calcium that controls or holds acidity within the range suitable for the desired

[1] MORGAN, M. F., The Universal Soil Testing System, *Connecticut Agr. Exp. Sta., Bull.* 392, pp. 129-159, 1937. This publication contains references to much of the recent literature on this subject.

legumes simultaneously supplies them with an abundance of active calcium for optimum growth. And if the calcium needs of legumes are satisfied, few other crops in the rotation are likely to require additional liming.

The Maintenance of Active Organic Matter and Nitrogen.—The maintenance of an adequate supply of active organic matter and nitrogen was discussed in Chap. XII and requires no discussion here but only mentioning, to complete the outline of soil treatment for the maintenance of productivity.

The Addition of Phosphorus.—As previously stated, soils in this country are rather generally deficient in available phosphorus for most crops. Cropping without fertilization over a period of years markedly reduces yields. The addition of phosphorus, limestone, and manure restores yields to the level that prevailed before depletion began. This treatment along with rotation produced yields of corn materially above those of 50 years earlier in Illinois. Because of the unquestioned need of phosphorus for crops and their known response to its application, liberal, regular use of phosphorus is the key to the maintenance of general productivity of many American soils.

Provision of Available Potassium.—Many heavy soils in the United States are well supplied with potassium. This is especially true in the glaciated area, up to 50,000 pounds and more of potash to the acre being found in the topsoil of some areas. The return of manure, owing to the fact that animals retain little of the potassium in their feed, supplies much of this element. A 10-ton application to the acre of average farm manure, for example, supplies around 100 pounds of potash which goes a long way toward supplying potash for a 4-year rotation of grain and forage crops. Moreover, additional potash is available from crop residues and from the soil itself.

Coarse sandy and gravelly mineral soils, unmanured, in general fail to supply most grain and forage crops with an adequate supply of available potassium for satisfactory yields. And if little or no manure is used on medium- and heavy-textured mineral soils, the addition of potassium in fertilizer materials may sometimes increase yields to a marked extent.

Following a Desirable Rotation of Crops.—The desirability of rotating crops was discussed in Chap. XVII. Its place in a rational program for the maintenance of the yields of grain and

forage crops needs only to be indicated here. The long-continued experimental work with soils and crops in Ohio and Illinois indicates the important place of desirable rotations in a program for maintaining productivity or for building it up on soils that have been depleted by exhausting systems of farming.

The Fertilization of Grain and Forage Crops.—The first step in the fertilization for grain and forage crops over much of the humid area of this country is the growing of legumes. If the reaction of the soil is unfavorable, this condition must first be corrected by the use of lime. The first-year growth of the new seeding of legumes for hay is usually left to go back into the soil or is pastured off. The hay is usually fed, and the manure returned to the soil. Conservation of the nutrients, particularly the nitrogen, in the manure is essential for best results. In addition, green manures consisting of a mixture of leguminous and nonleguminous plants may be used to distinct advantage in the areas that have relatively long growing seasons.

The second step automatically follows the first in that the manures, residues, and green manures return available potassium to the soil. Furthermore, the decomposition of the organic materials tends to aid in bringing potassium from the minerals of the soil into available form. Except as outlined in the section on Provision of Available Potassium, this use of organic materials should go far toward supplying grain and forage crops adequately with potassium.

The third step is the application of phosphorus in suitable form and condition. Phosphorus may be returned to the soil in farm manures and crop residues, in superphosphate or other manufactured forms, in basic slag, or in rock phosphate. Complete fertilizers are also a suitable source of this element.

The rate of application of phosphorus for grain and feed crops, including pastures and other forage crops, varies somewhat with conditions. The use of 20 to 30 pounds or occasionally more of actual phosphoric acid a year on the average for the rotation in mixed fertilizer or in the form of superphosphate appears to be sufficient for grain and forage crops. These quantities of phosphoric acid are supplied in 100 to 150 pounds of 20 per cent superphosphate. Similar or somewhat larger quantities of phosphorus in basic slag give good results. In the areas where finely

ground rock phosphate is used, 1,000 to 2,000 pounds an acre once in the rotation gives satisfactory results with grain and forage crops over a period of years on soils that are otherwise in favorable condition for these crops. The importance of the maintenance or even of increasing the supply of available phosphorus in soils can hardly be sufficiently emphasized.

Under some conditions, complete mixed fertilizers are used for grain and forage crops. In intensive production or under unfavorable temperatures or in late seasons, a moderate use of complete fertilizers is probably justified from the standpoint of cost and profit. In the main, however, the lower-cost fertilization of the low-return crops is definitely indicated.

The Fertilization of Cash and Vegetable Crops.—The variations in the fertilization of cash and vegetable crops in the different sections, even of the humid part, of this country are indeed very wide. Climate, soils, value of crops, intensity of the agriculture, and the anticipated profits from the use of fertilizer all have a bearing on local fertilizer practices. Ross and Mehring presented data on the use of some of the important fertilizers in the states that consume three-quarters of the tonnage in the United States. Their data are given in Table 63.

Of course, a great many other fertilizers are used for these and for other crops in the states named. The data show the variation both in the analyses used and in the amounts of fertilizer applied to the acre for any one crop as well as for the different crops in the various states. One point may be gleaned from this table, namely, that fertilizers that have been defined as low-analysis ones are still widely used. The 3-8-3 fertilizer with its total of 14 units appears in seven places, the 2-8-5 (15 units) in two places, and the 3-8-5 (16 units) in six places. In fact, present-day fertilizer economy would appear to dictate the use of higher analyses than many of those listed in Table 63. Out of the 52 fertilizers for the different states and crops, only 16 have a total of 20 units or more. The higher analyses in this list are used for potatoes. Relatively high-analysis fertilizers are used in quantities of 1,000 to 2,000 pounds to the acre and sometimes more for vegetable crops.[1]

[1] Many of the states have published an extension bulletin giving specific fertilizer recommendations with respect to soils and crops and the quantities of fertilizer recommended to the acre both with and without manure.

TABLE 63.—MOST COMMONLY USED GRADES FOR PRINCIPAL FERTILIZED CROPS IN STATES CONSUMING 75 PER CENT OF THE TOTAL FERTILIZER TONNAGE*

State	Cotton		Corn		Potatoes		Wheat		Tobacco	
	Analyses	Application per acre, pounds	Analyses	Application per acre, pounds	Analyses	Application per acre, pounds	Analyses	Application per acre, pounds	Analyses	Application per acre, pounds
Alabama	6-8-4	300	3-8-5	100	4-10-7	1,000				
Florida	3-8-5	300	4-8-4	200	4-8-4	2,000	......	...	3-8-5	1,000
Georgia	4-8-4	350	3-9-3	200	....	.....	2-10-4	200	3-8-5	1,000
Indiana	......	....	2-12-6	125	0-10-10	500	2-12-6	125	2-12-6	200
Maryland	......	...	2-12-4	100	6-6-5	2,000	2-8-5	250	4-8-12	800
Mississippi	4-8-4	300	4-8-4	150	6-10-7	1,000				
North Carolina	3-8-3	400	3-8-3	200	6-6-5	2,000	3-8-3	200	3-8-5	1,000
New York	......	......	4-12-4	300	4-8-7	2,000	2-8-10	250		
Ohio	......	...	2-12-6	125	4-8-8	1,000	2-12-6	200	4-10-6	400
Pennsylvania	......	...	2-8-5	200	2-8-10	1,000	3-12-6	250	4-8-7	750
South Carolina	3-8-3	400	3-8-3	200	6-6-5	2,000	3-8-3	200	3-8-5	600
Virginia	0-10-4	400	3-8-3	200	6-6-5	2,000	0-16-0	300	3-10-6	1,000
Louisiana	4-8-4	200	......	...	4-12-4	800				
Maine	......	...	3-10-6	600	4-8-10	2,000				

* ROSS, W. H., and A. L. MEHRING, *Yearbook of Agriculture*, Soils and Men, p. 539, U.S. Department of Agriculture, 1938.

Questions

1. How essential is it that the productivity of land be maintained over the long term?

2. To what extent was the productivity of Ohio soils reduced by continuous cropping according to the results obtained at the Ohio Agricultural Experiment Station?

3. What were the effects on yields of 50 years of continuous cropping at the Illinois Agricultural Experiment Station?

4. How were yields affected in Illinois by the application of limestone, manure, and rock phosphate?

5. Discuss the effects of rotating crops as compared with continuous cropping to corn in Illinois and to wheat and corn in Ohio.

6. Discuss the use of the "quick" chemical soil tests.

7. Outline a complete plan for the long-term maintenance of the productivity of the soils in your locality.

CHAPTER XIX

THE ORIGIN OF ORGANIC DEPOSITS AND PEAT SOILS AND THEIR MANAGEMENT

Mineral soils are composed largely of inorganic materials; yet such soils all contain some organic matter. Organic soils, in contrast, always contain much higher percentages of organic matter. In fact, peat soils often carry as much as 85 or 90 per cent of organic matter and only 10 to 15 per cent of mineral matter These differences suggest that the conditions under which organic soils were formed must have been entirely different from those under which many mineral soils were formed.

The Formation and Accumulation of Organic Deposits.—In order that organic matter may accumulate in large quantities, it is necessary to have permanent water in a depression or basin (Fig. 162). Basins were formed in various ways. At the close of the ice age, as the result of glacial action, many depressions were left in the northeastern part of the United States. In the coastal areas, such basins have sometimes originated from what was formerly an arm of the ocean. In places, shore currents built up barriers or dams and thus formed lagoons. In other instances, the elevation of the land produced a partial stoppage of the drainage into the sea. Much peat was formed in cool to cold climates; however, some deposits were built up in relatively warm sections, such as those of the Florida Everglades and the California Coast.

An example of a typical mature peat profile, such as may be found in New York,[1] shows how the peat was formed (Fig. 163). At the bottom of the profile is a layer of sedimentary peat that was formed by the accumulation of the remains of plants under water. When a sufficient depth of this material had accumulated, conditions became more suitable for the growth of other water-loving plants, especially the reeds, sedges, cattails, and grasses. The remains from these larger plants accumulated

[1] WILSON, B. D., and E. V. STAKER, The Character of the Peat Deposits of New York, *Cornell Univ. Agr. Exp. Sta.*, *Mem.* 149, 1933.

more rapidly and soon formed a layer of fibrous peat. Not long after the reeds and sedges came the bog and swamp plants. A condition favorable for shrubs followed. The cranberry, which is so common today in certain bogs, is typical of the shrubs. The alders, willows, birches, oaks, and tamaracks, also, became firmly established. With the complete filling of the bog and a sufficient lowering of the water table, other trees, such as the

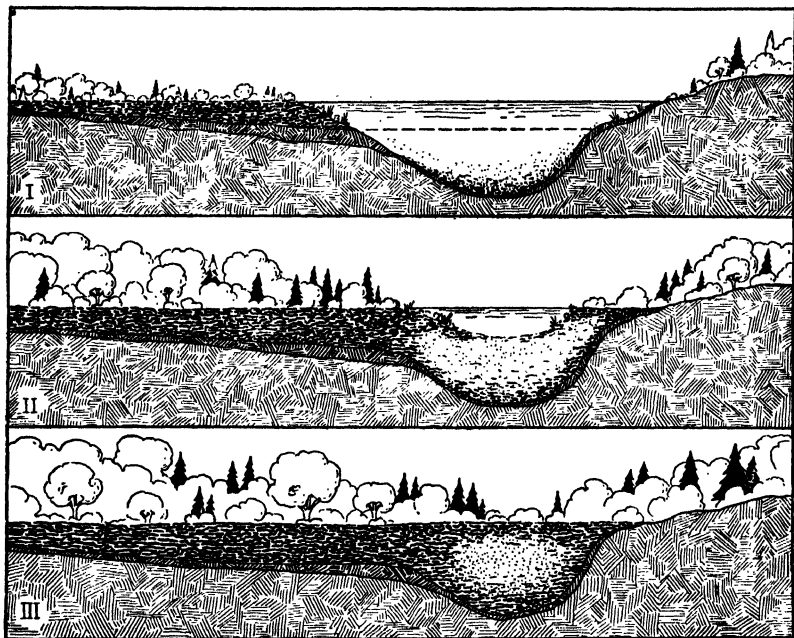



FIG. 162.—The formation of organic soils. Organic matter accumulates in the shallow water and on the edges of lakes and ponds as shown in I. As accumulation proceeds the amount of open water becomes less and less, II, until finally the depression is completely filled with organic matter, III, and no open water remains. (*Adapted from drawing by A. P. Dachnowski-Stokes.*)

maple, ash, and elm and even the conifers, became important. These woody plants formed the topmost layer of the profile. This is shown in Fig. 163 as woody peat.

It should be emphasized that the foregoing discussion of layers is an example of only one type of peat profile, a northern one. These layers may be interchanged, or any one layer may be absent entirely. It should be noted that the layers are named from the dominant vegetative material composing them, but they may contain in addition an admixture of other plants.

As long as organic matter is covered with water so that the air is excluded, only partial decomposition takes place. Some of the hydrogen may be removed as water or as hydrogen sulphide, and a relatively small amount of carbon is lost as carbon dioxide, CO_2, and methane, CH_4. Such decay is brought about by the

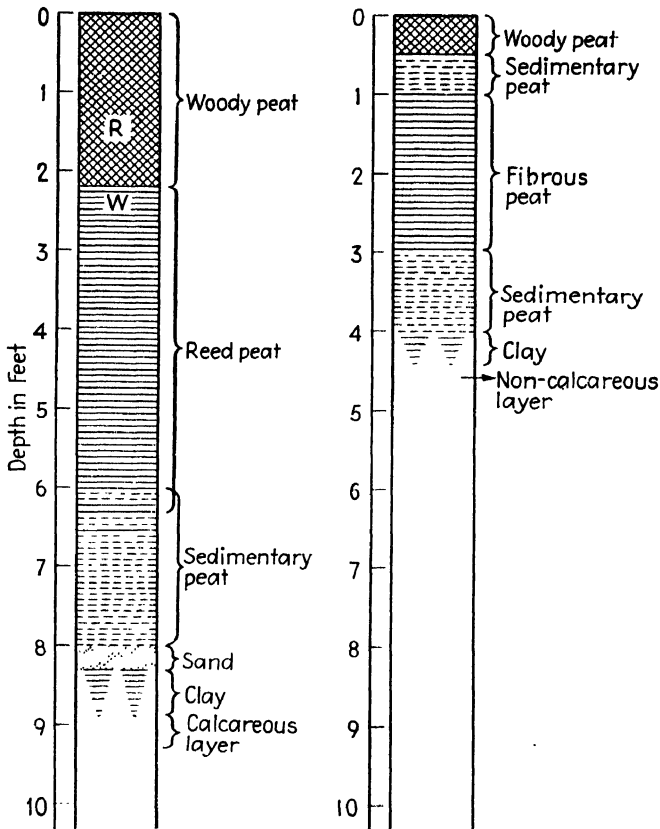



FIG. 163.—Representative profiles of peat in New York. *R* = reedy material in the wood peat and *W* = woody material in the reed peat. (*Courtesy of B. D. Wilson and E. V. Staker.*)

fungi and anaerobic bacteria. If the position of the water table is lowered with respect to the surface of the soil, either by complete filling of the bog or by natural drainage, the decomposition of the surface layers is greatly accelerated. Air then penetrates the surface of the peat and supplies the soil organisms with oxygen. This oxygen enables them to bring about decomposition of the organic matter.

The Physical Characteristics of Organic Soils.—Color, volume weight, structure, water-holding capacity, specific heat, and the ability to absorb and retain the ions of calcium, potassium, and hydrogen are the more important physical characteristics of peat. They are all dependent upon the organic matter present.

Color, the most striking visual characteristic of peats, varies from light brown to almost black. The nature and depth of color depend upon a number of factors such as the extent of decomposition of the plant residues, their original nature, the degree of oxidation, and the moisture content. If well drained, the surface soil warms up quickly because the dark color enables the soil to absorb considerable radiant heat.

There is another property of peat that is of particular importance in the growth of crops. This is the relative inability of peats to conduct heat. And, because of this property, organic matter, of which peat is largely composed, is often used for insulating purposes. In bright sunshine, well-drained peat warms up rapidly on the immediate surface. However, because of its high organic content, the heat penetrates below the surface very slowly. For this reason, the heat that is absorbed and conducted down into the peat is lost to the atmosphere at a retarded rate. Radiation from the surface of black peat, on the other hand, is rather rapid.

The volume weight of organic soils increases with the degree of decomposition and with increasing mineral content. In general, organic soils are characterized by low volume weights, varying from around 0.2 to 0.6. Peats and mucks then may be expected to weigh from about 500,000 to 1,000,000 pounds an acre 7 inches deep.

The structure of peats depends on the nature of the materials from which they were derived, particularly on their state of decomposition. Soil reaction also plays an important role. Peat soil derived from the decomposition of woody plants is more friable than that which originated from reeds and sedges.

The capacity of peat soils to absorb and to retain water is much greater than that of mineral soils. In working with peat samples from various parts of the United States, Feustel and Byers[1]

[1] Feustel, I. C., and H. G. Byers, The Physical and Chemical Characteristics of Certain American Peat Profiles, *U.S. Dept. Agr., Tech. Bull.* 214, 1930.

found their water-holding capacity to vary from about 300 to over 3,000 per cent. It was highest with the sphagnum peat but was not particularly uniform with regard to the type of plant that supplied the organic material comprising the samples.

Some striking differences are found between mineral and peat soils. One of them is revealed when a comparison is made of their respective capacities for holding plant nutrients in an available condition. An average peat soil, high in organic matter, is capable of absorbing and holding ten to more than twelve times (by weight) as much calcium or potassium as a normal mineral soil. Obviously, this difference may be attributed to the high organic content of the peat soil. In addition, the high permeability of peat for water, its notable shrinkage on drying, and its relatively great buffering power should be mentioned.

The Classification of Organic Materials.—At present, no generally acceptable method for the classification of the organic soils of the United States as a whole exists although some attempts have been made along this line.[1]

In a very general way, they may be divided into two groups, *peat* and *muck*. The term *peat* has been used to designate mate-

[1] DACHNOWSKI-STOKES, A. P., and V. AUER, American Peat Deposits, *Handbuch der Moorkunde*, Band 7, pp. 140, 1933.

———, Essentials of a General System of Classifying Organic Soils, *Trans. Third Internat. Congress Soil Science*, Vol. 1, pp. 416–418, 1935.

A separation on the basis of the kinds of plant residues has been suggested by Dachnowski (Quality and Value of Important Types of Peat Material, *U.S. Dept. Agr.*, *Prof. Paper* 802, 1919). (See also, summary by Lyon and Buckman "The Nature and Properties of Soils," The Macmillan Co., New York, 1943.)

(1) Sedimentary—aquatic plants such as water lilies, pondweed, hornwort. (2) Fibrous—sphagnum and other mosses, sedges, reeds, cattails. (3) Woody—deciduous and coniferous trees, shrubs, and undergrowth of various kinds.

This classification does not consider the type or degree of decomposition or the soil profile. An attempt to classify peats has been made in California. Cosby and Shaw (Character and Classification of the Organic Soils of the Delta Region, California, *Trans. Internat. Congress Soil Science*, Vol. 1, pp. 413–416, 1935) state that "organic soils can be differentiated in accordance with the same principles that are applied to mineral soils."

It seems, however that considerable work still remains to be done before the organic soils of United States can be classified with the same degree of assurance as the mineral soils.

rials in which the structure of the plants is still more or less apparent. *Muck*, on the other hand, has been used for well-decomposed plant remains, the identity of which cannot be determined. From this point on, the term peat is used for organic soils that contain more than 50 per cent of organic matter and less than this proportion of mineral matter. In contrast, muck is used to designate those soils which contain between 20 and 50 per cent of organic matter. In some sections, however, farmers refer to organic soils in general as muck.

Organic soils are sometimes spoken of as being of high-lime, intermediate,[1] or low-lime content, depending upon the amount of calcium present. However, such usage is not very common in this country.

The Occurrence of Marl in Association with Organic Deposits.—Often deep-water muck or the sedimentary layer of a peat soil profile is underlaid by a gray or white material known as *marl* (see Fig. 113). Marl is an impure form of calcium carbonate. According to Berquist, Musselman, and Millar,[2] the marl present in swamps and lakes may have accumulated in three different ways: (1) by chemical precipitation, (2) by accumulation by plants, and (3) by accumulation by animals.

Water flowing over limestone rock or through calcium-bearing materials dissolves out calcium and becomes impregnated with it in the form of the bicarbonate. As this water in turn flows into basins or depressions, the calcium bicarbonate loses some of its carbon dioxide and water. Calcium carbonate, therefore, is precipitated.

Under certain conditions, the precipitation of calcium carbonate may be greatly aided by such plants as *chara*, *nitella* and *Potamogeton*. Such plants live only in lime-containing waters and are able to extract large quantities of calcium from the water. When the plants die, their remains, which have become quite calcareous in nature, are deposited in the swamp or lake. This material is usually cream colored when pure but may vary from white to black depending upon the amount and degree of oxida-

[1] Alway, F. J., Agricultural Value and Reclamation of Minnesota Peat Soils, *Minnesota Agr. Exp. Sta., Bull.* 188, p. 8, 1920.

[2] Berquist, S. B., H. H. Musselman, and C. E. Millar, Marl, Its Formation, Excavation, and Use, *Michigan Agr. Exp. Sta., Spec. Bull.* 224, pp. 5, 6, 1932.

tion of iron or the plant material present. Chemically precipitated lime is often found in marl.

Shells also occur commonly, but in the opinion of Dachnowski[1] the shell remains from mollusks are relatively unimportant in the accumulation of marl.

The Location and Acreage of Organic Soils in the United States.—The most important peat deposits of the United States are found in two general regions. One of these, which has been

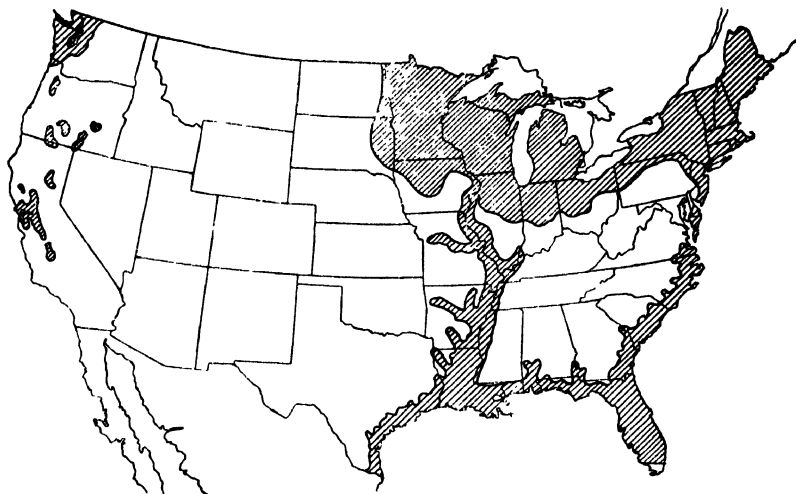



FIG. 164.—Areas in the United States in which peat and other organic deposits may occur. Not all of the shaded area consists of organic soils. Rather the organic soils may be expected to occur mainly within the shaded areas. In addition small acreages are found in Idaho, Montana, Colorado, Utah, and Nebraska. (*Redrawn from information from several sources.*)

referred to as the "northern," or "glacial," region, practically coincides with the part of the country that was covered by glaciers during the Pleistocene epoch. It includes Minnesota, Wisconsin, Michigan, New York, eastern South Dakota, the northern parts of Iowa, Illinois, Indiana, and New Jersey, and smaller acreages in Pennsylvania and the New England states. The climate is characterized by relatively low temperature and high humidity, especially during the growing season.

A second region (a warmer one) is found along the Atlantic Coast and embraces southern Delaware, the coastal parts of

[1] DACHNOWSKI, A. P., Quality and Value of Important Types of Peat Material, *U.S. Dept. Agr., Prof. Paper* 802, p. 21. 1919.

Maryland, Virginia, North and South Carolina, Georgia, and all of Florida. This section of the United States has a fairly heavy rainfall and a relatively high humidity, as well. Because of the gradual subsidence of the coastal plains, the deposits occur in drowned valleys and lagoons. Farther inland, peat is found on flat imperfectly drained areas. Both swamps and marshes are found in which the organic material consists for the most part of trees, sedges, and grasses.

A third but much smaller region than the two just mentioned consists of a narrow belt of land along the Gulf Coast; a fourth, the coast of California, the valleys of the San Joaquin and Sacramento rivers, and the basins of several lakes and rivers in the states of Oregon and Washington.

A map showing the areas in which important organic deposits may occur in the United States is found in Fig. 164.

In order to obtain information concerning the acreage of organic soils (peat and muck) and the proportion of them under cultivation, including pasture, inquiry was made of a worker in soils in each state. The estimates made by them are given in Table 64.

The total area of organic soils in the United States according to the state experiment station workers is somewhat more than 25 million acres. Of this area, 2½ million acres, or nearly 11.0 per cent, is in agriculture including pasture, according to these estimates.

The Chemical Composition of Organic Soils.—The analyses of some typical peat soils are given in Table 65.

Peat soils differ markedly from mineral soils not only in organic matter but also in their content of nitrogen, phosphoric acid, and potash. They are well supplied with nitrogen usually containing not less than 0.5 per cent. Samples have been analyzed which showed as much as 4 per cent of this element. However, much of the nitrogen in peats may remain unavailable to plants, especially in peats and mucks of low lime content.

The total amount of phosphorus in peat soils is often greater than that in mineral soils, but the studies which have been made indicate that phosphorus, too, may be quite unavailable. As shown in Table 65, the amount of potash in peat is very small in comparison with that in most mineral soils; unfertilized organic soils often contain less than 0.1 per cent of potash. Mineral

TABLE 64.—ESTIMATED AREA OF ORGANIC SOILS IN THE UNITED STATES*

State	Acreage of peat and muck soils		
	Total	In agriculture	Per cent
Arkansas†	1,000	None	
California	300,000	291,000	97
Colorado	4,000	4,000	100
Connecticut	31,000	28,000	90
Delaware	100,000	None	
Florida	2,275,000	45,500	2
Georgia	40,000	2,000	5
Idaho	33,000	23,100	70
Illinois	160,000	120,000	75
Indiana	400,000	320,000	80
Iowa	160,000	128,000	80
Louisiana	3,000,000	None	
Maine	250,000	None	
Massachusetts	337,600	33,760	10
Michigan	4,000,000	200,000	5
Minnesota	7,000,000	200,000	3
Mississippi	40,000	None	
Missouri	5,000	5,000	100
Montana	25,000	5,000	20
Nebraska	10,000	10,000	100
New Hampshire	121,600	None	
New Jersey	500,000	40,000	8
New York	400,000	32,000	8
North Carolina	920,000	46,000	5
Ohio	55,000	46,000	84
Oregon	125,000	125,000	100
Pennsylvania	20,000	4,000	20
Rhode Island	32,200	4,200	13
South Dakota	2,000	2,000	100
Texas	5,100	None	
Utah	21,000	4,200	20
Vermont‡	....	....	
Virginia	128,000	6,400	5
Washington	2,138,000	200,000	9
West Virginia	2,000	400	20
Wisconsin	2,560,000	768,000	30
Wyoming	1,000	None	
Total	25,202,500	2,697,560	Aver. 10.70§

* According to the U.S. Department Agriculture, *Yearbook for Agriculture*, 1938, p. 1128, there are 79 million acres of peat soils in the United States. Obviously, a different basis for estimating acreages was used than that employed by the state experiment station workers quoted in this table.

† Alabama, Arizona, Kansas, Kentucky, Maryland, Nevada, New Mexico, North Dakota, Oklahoma, South Carolina, and Tennessee reported as having negligible acreages or no organic soils. ‡ No estimate available. § Average for states reporting organic soils in agriculture.

TABLE 65.—CHEMICAL ANALYSES OF TYPICAL ORGANIC SOILS FROM DIFFERENT SECTIONS OF THE UNITED STATES

Source	Depth, inches	Volatile matter	Constituents in the soil (dry basis, per cent)			
			N	P_2O_5	K_2O	CaO
Minnesota (high lime)[b]	0– 8	79.8	2.78	0.24	0.10	3.35
Minnesota (low lime)[b]	0– 8	94.0	1.70	0.16	0.04	0.31
Minnesota (low organic)[b]	0– 8	59.7	2.35	0.36	0.17	2.52
New York (high lime)[c]	0–12	86.1	2.34	0.20	0.18	5.80
New York (low lime)[c]	0–12	94.2	1.26	0.15	0.10	0.60
Maine (sphagnum)[d]	2– 4, 5– 8	95.6	0.75[a]	0.11	0.04	0.44
North Carolina (heath)[d]	0– 9	95.2	1.89[a]	0.17	0.04	0.43
Florida (custard apple)[e]	0–12	44.5	1.47	0.48	0.05	3.81
Florida (saw grass)[e]	0–12	87.1	2.79	0.41	0.04	5.20
Washington (woody sedge)[d]	0– 6	89.2	3.52[a]	0.43	0.09	1.29
Oregon[f]	....	....	1.22	0.50	0.26	4.12

[a] Basis, 100 parts organic matter.
[b] ALWAY, F. J., Agricultural Value and Reclamation of Minnesota Peat Soils, *Minnesota Agr. Exp. Sta., Bull.* 188, 1920.
[c] WILSON, B. D., and E. V. STAKER, The Chemical Composition of the Muck Soils of New York, *Cornell Univ. Agr. Exp. Sta., Bull.* 537, 1932.
[d] FEUSTEL, I. C., and H. G. BYERS, The Physical and Chemical Characteristics of Certain American Peat Profiles, *U.S. Dept. Agr., Tech. Bull.* 214, 1930.
[e] HAMMAR, H. E., The Chemical Composition of Florida Everglades Peat Soils, *Soil Science*, Vol. 28, p. 5, 1929.
[f] POWERS, W. L., and W. W. JOHNSTON, The Improvement and Irrigation Requirement of Wild Meadow and Tule Land, *Oregon Agr. Exp. Sta., Bull.* 167, p. 9, 1920.

soils, in contrast, carry as much as 2 to 4 per cent of potash.

The greatest variation is found with regard to lime, different samples ranging all the way from about 0.3 per cent to more than 7 per cent, depending upon the kind of peat and its location.

Some peat soils have been found to be deficient in the trace, or minor elements, particularly copper,[1] manganese,[2] and boron.

[1] KNOTT, J. E., The Effect of Certain Mineral Elements on the Color, and Thickness of Onion Scales, *Cornell Univ. Agr. Exp. Sta., Bull.* 552, 1933.
[2] BRYAN, O. C., The Stimulating Effect of External Applications of

At the present time, considerable work is under way in an effort to learn whether need exists for other elements in this group.

The Reclamation of Organic Soils.—The area of good, virgin organic soils in the United States that is suitable for farming under present economic conditions is regarded as being relatively small. Clearing of the virgin deposits has been in progress for many years. Today, the remaining areas consist largely of the less desirable peats. In some cases, land that once was tilled has been abandoned. Climatic conditions may have been unfavorable or certain economic factors may not have been sufficiently understood, or abandonment may have been brought about by poor soil conditions. These possibilities emphasize the importance of careful investigation *before* any plan for reclaiming peat deposits is decided upon.

Adaptability of the Land.—Previous to spending time or money in preparing an area for crop production, the suitability of the land for cropping should be determined. The character of the soil material, degree of acidity, possibility of drainage, depth of the peat, and approximate cost per acre of clearing are some of the important points that need attention. In some states, the matter of occurrence of frost must also be included as it may often be the limiting factor in plant growth. It is often helpful in settling these questions to get the suggestions and advice of the state agricultural experiment station workers.

Drainage.—Once the reclamation of a peat area has been decided upon, the first major task is drainage. Open drainage ditches are usually cut through the bog at intervals of 50 to 150 feet, a year or so ahead of clearing off the trees or other vegetation. This ditching removes the excess water, promotes aeration, and leaves the surface sufficiently firm for men, horses, or tractors to work on. The proper distance between the ditches, particularly the laterals, depends partly on the character of the peat but mostly on the rainfall. It is obvious that in regions of relatively high rainfall the ditches must be closer together than in regions of comparatively low rainfall. Tile drains may be used under shallow peat or muck soils, but in deep organic soils the tiles often settle unevenly. Because of this difficulty with tile, open ditches are generally used for draining organic soils.

Copper and Manganese on Certain Chlorotic Plants of the Florida Everglades Soils, *Jour. Amer. Soc. Agron.*, Vol. 21, pp. 923–933, 1929.

In the installation of any drainage system, it is just as important that provision be made for water-level control as it is to get rid of the excess water. If the distance to the water table can be controlled, it will be possible during dry seasons to keep the moisture content of the soil at the optimum, thus resulting in much larger yields than would otherwise be possible. With small, open drainage ditches, such control is accomplished by placing gates or dams of sod in the ditches during dry periods and removing them during wet ones. If tile drains have been installed, raising the water table is simply a matter of closing the tile outlets.

Removal of the Vegetative Cover.—If the natural vegetation on a drained peat deposit consists only of sedges, grasses, shrubs, or similar plants, the problem of preparing the land for plowing is simple. A little handwork may be all that is necessary. Frequently, such areas are burned over when the land is first prepared for cropping. The burning of brush and other trash on the surface should not be confused, however, with the burning of the peat itself for the purpose of meeting the chemical requirements of crops. The latter practice is not recommended.[1] Any burning on organic soils should be confined to times when the organic material is wet below the surface.

Peat deposits that have a woody surface layer may be covered with forest, and then the problem of reclamation is more difficult and more expensive. However, the added expense may be partly offset by the sale of the timber. In addition, the high quality of peat land having a woody surface layer is a point not to be forgotten.

Plowing.—It is often possible as well as desirable to grow a crop the same year that an area is cleared, provided that the reclamation was started early enough. In that event, the first plowing may not be a thorough one, particularly if the area was previously covered with trees. No attempt is usually made to remove all of the roots at this time, but only those nearest the surface and most likely to interfere later with the use of tillage implements. Such a practice permits the remaining roots to decay gradually and facilitates their removal at subsequent plowings.

[1] ALWAY, *op. cit.*, p. 109.

The High Value of Organic Soils.—With the possible exception of the cereal crops, it is possible under favorable climatic conditions to grow many of the same crops on peat soils that can be grown on mineral soils in the same locality. However, peat soils are best adapted to the growth of vegetables, and it is in this respect that they are superior to mineral soils. Large yields of carrots, celery, lettuce, onions, and potatoes are possible. Knot,[1] for example, states that on the muck soils of New York 1,000 boxes or more of celery (2 dozen stalks) per acre are sometimes obtained. In Table 66, the average yields of some vegetables when grown on both peat and mineral soils are compared.

TABLE 66.—COMPARISON OF THE YIELDS OF CERTAIN VEGETABLE CROPS WHEN GROWN ON PEAT AND MINERAL SOILS, RESPECTIVELY

Crop	Unit of measure	Yield per acre				
		New York		Michigan		United States,‖ all soils, av. 1919–29
		Muck soils	All soils, av. 1929–29	Muck soils, 1919–27	All soils,‖ av. 1919–27	
Celery....	N.Y. "two-thirds" crates	454*	304	....	...	286
Lettuce...	Crates of 4 dozen heads	252†	179	....	...	207
Onions...	Bushels	620‡	346	339§	307	287

* Average yield on 398 acres for the year 1928. Data from *Cornell Bull.* 517, p. 16, 1931.
† State average for the years 1927–1931. Data from *Cornell Bull.* 564, p. 4, 1933.
‡ Average mean yield for 1929 from 94 farms comprising 948 acres. From *Cornell Bull.* 510, p. 10, 1930.
§ Data from *Michigan Special Bull.* 168, p. 5, 1927.
‖ Data from U.S. Department of Agriculture, *Yearbook*, 1925, 1930.

The superiority of organic soils in the production of such crops is clearly evident. Just as an investment is valued according to its earnings, peat land is worth what the net income will pay interest on. Larger yields will ordinarily result in greater income and therefore higher land values.

[1] KNOTT, J. E., Lettuce Production on the Muck Soils of New York, *Cornell Univ. Agr. Exp. Sta., Bull.* 564, p. 4, 1933.

The Fertilization of Crops on Peat and Muck Soils.—Peat soils, like mineral soils, are often deficient in one or more of the three major fertilizer constituents, nitrogen, phosphorus, and potassium. In addition, they may be low in lime. Where red clover, timothy, or corn is to be grown, newly cleared peat land high in lime may require no initial fertilizer treatment.[1] However, after a few years, the supply of potassium and phosphorus

FIG. 165.—An area of peat in New York. This area of peat occurs on the Lake Plain. Celery and potatoes occupy large acreages in this locality. Farther west lettuce and onions are grown in large quantities. (*Courtesy of H. O. Buckman.*)

is depleted to the point where they become limiting factors and must be supplied as fertilizer.

For the growth of ordinary field crops or for pasture, lighter applications of fertilizer suffice than are needed on land where vegetable crops are grown. The addition of nitrogen, especially, on high-lime peats, may be omitted. It has been found for example in Michigan[2] that for the growth of general crops 300 to 500 pounds of an 0-12-12 fertilizer is sufficient as an initial treatment. Afterward the annual application is reduced to one-fourth or one-half of these amounts.

The fertilization of peat land for vegetable crops in recent years has received considerable attention (Fig. 165). The states of

[1] ALWAY, *op. cit.*, p. 71.

[2] MCCOOL, M. M., G. M. GRANTHAM, and P. M. HARMER, Standard Fertilizers for Michigan, *Mich. Circ. Bull.* 53, 1930.

Ohio,[1] Indiana,[2,3,4] Florida,[5] Michigan,[6,7] and New York[8,9,10,11,12] have been most active. The proper fertilization of vegetables has been shown by Harmer[7] (page 47 in work cited), with special reference to onions, to depend upon (1) type of soil, (2) depth of soil, (3) length of time since reclamation, (4) time of planting the crop, and (5) natural influence of the soil on the period of growth.

It is not possible to discuss in this chapter the many details associated with the fertilization of specific vegetable crops. The reader is accordingly referred to the publications cited. Only a few illustrations can be given.

Regarding the fertilization of celery, Comin[1] found that under Ohio conditions the best results followed the application of 1,000 pounds per acre of 2-8-16 just before setting. This is followed by 500 pounds of the same analysis applied as a side dressing 3 weeks later and again 6 weeks after the plants were set. Celery responds to lime in addition if the soil is very acid.

For early onions, Harmer[7] suggests the use of 800 to 1,500 pounds of 3-12-18 on low-lime, newly cleared land, or on shallow

[1] COMIN, DONALD, Horticulture at the Ohio Agricultural Experiment Station, *Ohio Agr. Exp. Sta., Spec. Circ.* 30, p. 34, 1930.

[2] CONNER, S. D., and J. B. ABBOTT, Unproductive Black Soils, *Purdue Agr. Exp. Sta., Bull.* 157, pp. 237–261, 1912.

[3] BETTIE, J. H., Truck Growing on Muck in the Kankakee Marsh of Northern Indiana, *Jour. Amer. Peat Soc.*, Vol. 14, pp. 33–37, 1921.

[4] BROWN, H. D., The Culture of Onions in Indiana, *Purdue Agr. Exp. Sta., Circ.* 158, p. 7, 1928.

[5] FIFIELD, W. M., Potato Growing in Florida, *Florida Agr. Exp. Sta., Bull.* 295, p. 29, 1936.

[6] EDMOND, J. B., Celery Culture in Michigan, *Michigan Agr. Exp. Sta., Spec. Bull.* 157, p. 4, 1926.

[7] HARMER, P. M., The Management of Michigan Muck Soils for the Production of Onions, *Michigan Agr. Exp. Sta., Spec. Bull.* 168, p. 18, 1927.

[8] KNOTT, J. E., Celery Production on the Muck Soils of New York, *Cornell Univ. Agr. Exp. Sta., Bull.* 517, p. 14, 1931.

[9] KNOTT, J. E., Growing Onions on the Muck Soils of New York, *Cornell Univ. Agr. Exp. Sta., Bull.* 510, p. 9, 1930.

[10] KNOTT, J. E., Fertilizing Onions on Muck Soils, *Cornell Univ. Agr. Exp. Sta., Bull.* 650, p. 18, 1930.

[11] KNOTT, J. E., The Effect of Certain Mineral Elements on the Color and Thickness of Onion Scales, *Cornell Univ. Agr. Exp. Sta., Bull.* 552, 1933.

[12] Fertilizer Recommendations for New York, *Ext. Bull.* 281, 1939.

peat if there is a tendency toward late maturity. The use of the same quantity of a 4-8-24 is advised on old, deep, high-lime peat that matures the onions too early.

Knott[1] distinguished between newly cleared woody muck and newly cleared reed and sedge muck in making recommendations for the initial application of fertilizers for lettuce. For the former, he found 1,000 pounds of 0-10-10 most satisfactory and for the latter 1,000 pounds of 4-8-10 or 4-8-12. He also differentiates between soil which has been cultivated 3 to 10 years and that which has been cropped longer than 10 years.

Potatoes grown on the Everglades soils of Florida according to Fifield[2] are usually fertilized with either the 0-10-12 or 0-8-12 analysis. The fertilizer is nearly always applied at planting time. The rate used is 200 to 500 pounds an acre. It will be noted that nitrogen is not included because enough of this element apparently is present in the soil in a readily available form to take care of the needs of potatoes.

It is not uncommon to find a deficiency in peat soils of one or more of the trace elements. The Everglades soils of Florida,[3] for example, are frequently lacking in manganese. Manganese sulphate, therefore, is added to most of the fertilizers used in this area. On the saw-grass peat of Florida, copper applied as copper sulphate is sometimes beneficial.[4] It is usually broadcast over the land before the initial cultivation at rates of 50 to 100 pounds an acre. Knott[5] states that "on many mucks in New York, copper sulphate should be applied in addition to nitrogen, phosphoric acid, and potash, primarily to improve the color and thickness of onion scale[6] and the keeping quality of the onions." An application of 300 pounds of finely ground copper sulphate to the acre is recommended. No more is applied until the effect of the first treatment begins to disappear.

[1] KNOTT, J. E., Lettuce Production on the Muck Soils of New York, *Cornell Univ. Agr. Exp. Sta.*, *Bull.* 564, p. 26, 1933.

[2] *Op. cit.*

[3] BRYAN, *op. cit.*

[4] BRYAN, *op. cit.*

[5] KNOTT, J. E., Fertilizing Onions on Muck Soils, *Cornell Univ. Agr. Exp. Sta.*, *Bull.* 650, p. 18, 1930.

[6] KNOTT, J. E., The Effect of Certain Mineral Elements on the Color and Thickness of Onion Scales, *Cornell Univ. Agr. Exp. Sta.*, *Bull.* 552, 1933.

Questions

1. Under what conditions were organic deposits accumulated in the United States?

2. What are the outstanding characteristics of organic soils?

3. Distinguish between *peat* and *muck*.

4. Describe the formation of and show the relationship between peat and marl deposits.

5. In what parts of the United States do peat and muck soils occur?

6. What is the total estimated acreage of organic soils in the United States?

7. Compare the nitrogen, phosphorus, and potash content of organic with that of mineral soils.

8. Outline the procedure of draining, clearing, and bringing peat and muck soils under cultivation.

9. Account for the high value of organic soils under intensive cultivation.

10. Outline one system of fertilization for vegetables and another for feed crops on peat and muck lands. What is the difference in the fertilization of old as compared with newly cleared peat?

APPENDIX A

COMMON AND SCIENTIFIC NAMES OF CERTAIN PLANTS

Alder (*Alnus* sp.)
Alfalfa (*Medicago sativa*)
Alkali-heath (*Frankenia grandifolia*)
American beach grass (*Ammophila breviligulata*)
Apple (*Malus pumila*)
Ash (white) (*Fraxinus americana*)
Azalea (*Rhododendron nudiflorum*)
Barley (*Hordeum*)
Bean (*Phaseolus vulgaris* var.)
Bent grass (*Agrostis* sp.)
Bermuda grass (*Cynodon Dactylon*)
Birch (*Betula* sp.)
Blackberry (*Rubus allegheniensis*) and other *Rubus* sp.
Black locust (*Robinia pseudoacacia*)
Black medic (*Medicago lupulina*)
Blueberry (*Vaccinium corymbosum*)
Broom corn (*Sorghum* sp.)
Brussels sprouts (*Brassica oleracea* var. *gemmifera*)
Buckwheat (*Fagopyrum esculentum*)
Bull thistle (*Cirsium lanceolatum*)
Bur clover (Southern) (*Medicago hispida*)
Bur clover (Tifton) (*Medicago rigidula*)
Cabbage (*Brassica oleracea* var. *capitata*)
Canada thistle (*Cirsium arvense*)
Carrot (*Daucus Carota* var. *sativa*)
Cauliflower (*Brassica oleracea* var. *botrytis*)
Celery (*Apium graveolens* var. *dulce*)
Chard (*Beta vulgaris* var. *Cicla*)
Clover (alsike) (*Trifolium hybridum*)
Clover (crimson) (*Trifolium incarnatum*)
Clover (mammoth) (*Trifolium pratense* var.)
Clover (red) (*Trifolium pratense*)
Clover (white) (*Trifolium repens* var.)
Common sesbania (*Sesbania macrocarpa*)
Corn (*Zea Mays* var.)
Corn cockle (*Agrostemma Githago*)
Cotton (Sea Island) (*Gossypium barbadense*)
Cotton (upland) (*Gossypium hirsutum*)
Cowpea (*Vigna sinensis*)

Crab native (*Malus coronaria*)
Crabapple (*Malus angustifolia*)
Cranberry (*Vaccinium macrocarpon*)
Crotalaria (*Crotalaria striata* and *C. spectabilis*)
Cucumber (*Cucumis sativus*)
Dalea (*Dalea alopecuroides*)
Deering velvet bean (*Stizolobium Deeringianium*)
Eggplant (*Solanum melongena* var. *esculentum*)
Elderberry (*Sambucus canadensis*)
Elm (*Ulmus* sp.)
Florida beggarweed (*Meibomia purpurea*)
Foxtail (*Setaria glauca*)
Grapefruit (*Citrus maxima*)
Greasewood (*Sarcobatus vermiculatus*)
Hazelnut (*Corylus americana*)
Holly (American) (*Ilex opaca*)
Japanese honeysuckle (*Lonicera japonica halliana*)
Kentucky bluegrass (*Poa pratensis*)
Kudzu (*Pueraria hirsuta*)
Lamb's-quarters (*Chenopodium album*)
Laurel (*Kalmia latifolia*)
Lemon (*Citrus Limonia*)
Lespedeza (common) (*Lespedeza striata*)
Lespedeza (Korean) (*Lespedeza stipulacea*)
Lettuce (*Lactuca sativa*)
Lime (*Citrus aurantifolia*)
Long-podded sesbane, or pea-tree (*Sesbania macrocarpa*)
Maple (*Acer* sp.)
Marsh Samphire (*Solicornia europaea*)
Milkweed (*Asclepias* sp.)
Millet (broom corn) (*Panicum miliaceum*)
Millet (foxtail) (*Setaria italica*)
Millet (Japanese) (*Echinocloa frumentacea*)
Millet (pearl) (*Pennisetum glaucum*)
Morning-glory, or black bindweed (*Polygonum Convolvulus*)
Mullein (*Verbascum Thapsus*)
Muskmellon (*Cucumis Melo*)
Oak (*Quercus* sp.)
Oat (*Avena sativa*)
Onion (*Allium cepa*)
Orange (*Citrus sinensis*)
Orchard grass (*Dactylis glomerata*)
Parsnip (*Pastimaca sativa*)
Partridge pea (*Cassia Chamaechrista*)
Pea (Austrian winter) (*Pisum sativum* var. *arvense*)
Pea (Canada field) (*Pisum sativum* var. *arvense*)
Pea (garden) (*Pisum sativum*)
Pea (Tangier) (*Lathyrus tingitanus*)

Peach (*Prunus persica*)
Pigweed (*Amaranthus spinosus* or *A. retiflexus*)
Pigweed (*Chenopodium album*)
Pondweed (*Potamogeton* sp.)
Potato (*Solanum tuberosum*)
Poverty grass (*Danthonia spicata*)
Quack, or couch, grass (*Agropyron repens*)
Rape (*Brassica Napus*)
Raspberry (black) (*Rubus occidentalis*)
Raspberry (red) (*Rubus idaeus*)
Redtop (*Agrostis alba*)
Rhododendron (*Rhododendron* sp.)
Rice (*Oryza sativa*)
Rye (*Secale cereale*)
Salt bush (*Artiplex* sp.)
Salt reed grass (*Spartina cynosuroides*)
Saltwort (*Salsola* sp.)
Samphire (marsh) (*Salicornia europaea*)
Sesbania (*Sesbania macrocarpa*)
Sorghum (grain) (*Sorghum vulgare*)
Soybean (*Glycine Max*)
Spinach (*Spinacia oleracea*)
Squash (*Cucurbita maxima*)
Strawberry (*Fragaria* sp.)
Sudan grass (*Sorghum sudanense*)
Sugar beet (*Beta vulgaris*)
Sunflower (*Helianthus annuus*)
Sweet clover (white) (*Melilotus alba*)
Sweet clover (yellow) (*Melilotus* var.)
Sweet potato (*Ipomoea Batatas*)
Tamarack (*Larix laricina*)
Timothy (*Phleum pratense*)
Tobacco (*Nicotiana Tabacum*)
Tomato (*Lycopersicon esculentum*)
Trailing wild bean (*Strophostyles helvola*)
Trefoil (bird's foot) (*Lotus corniculatus*)
Trefoil (yellow) (black medic) (*Medicago lupulina*)
Turnip (*Brassica Rapa*)
Turnip (cowhorn) (*Brassica Rapa*)
Tussock grass (*Agrostis alba*)
Vetch (hairy) (*Vicia villosa*)
Vetch (monantha) (*Vicia monantha*)
Vetch (smooth) (*Vicia villosa* var.)
Vetch (woolly-pod) (*Vicia dasycarpa*)
Walnut (*Juglans nigra*)
Wheat (*Triticum sativum*)
Willow (*Salix* sp.)

APPENDIX B

APPROXIMATE EQUIVALENTS AND FORMULAS

Weights

1 ounce (avoirdupois)	= 28.4 grams
1 gram	= 0.0353 ounce (avoirdupois)
1 pound (avoirdupois)	= 454 grams
1 kilogram	= 2.2 pounds (avoirdupois)
1 gallon	= 231 cubic inches
1 gallon of water	= 8.34 pounds (avoirdupois)
1 cubic foot of water (7.48 gallons)	= 62.42 pounds* (avoirdupois)
1 liter	= 1.056 quarts

One inch of water over 1 square foot weighs 5.2 pounds.
One acre-inch of water weighs 226,512 pounds, or 113¼ tons.

Linear Measure

1 inch	= 2.54 centimeters
1 meter	= 39.4 inches, 3.28 feet

Square Measure

1 square foot	= 144 square inches
1 acre	= 43,560 square feet
1 square mile	= 1 section
1 square mile	= 640 acres

Cubic Measure

1 cubic inch	= 16.4 cubic centimeters
1 cubic foot	= 1,728 cubic inches

Temperature

Temperature, centigrade degrees	= (temp., Fahrenheit degrees − 32) × 5/9
Temperature, Fahrenheit degrees	= (temp., centigrade degrees × 9/5) + 32

Formulas

Circumference of circle	= diameter × 3.1416
Area of circle	= radius squared × 3.1416
Area of sphere	= 4 × radius squared × 3.1416
Volume of sphere	= (diameter cubed × 3.1416) ÷ 6
Volume of cylinder	= area of base × height

* 62.43 lb. at 4°C., 62.5 lb. often used for practical calculations.

INDEX

D

Q

R

S